Development of baseline data for long-term monitoring of sediment conditions at reference sites in Saint John Harbour, New Brunswick: benthic infaunal invertebrates and sediment contaminants 2011-2013

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by

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Abstract

Seasonal and annual monitoring of infaunal invertebrates and sediment contaminants was done at reference sites known to have historically low metals and polycyclic aromatic hydrocarbons (PAHs) in the Saint John Harbour, New Brunswick between 2011 and 2013. The objectives of this study were to generate baseline data to be used to develop a long-term monitoring program in the Harbour. Total abundance, richness, and diversity of invertebrates varied seasonally, annually, and spatially, and habitat-specific assemblages were identified in the inner and outer harbour. All sediment contaminants (19 metals; 16 priority PAHs) showed little variability among sites, seasons or years (typically < 5-fold), and only 2 (arsenic and nickel) metals exceeded guidelines across sites. Results were used to design a long-term monitoring program that could be used to assess cumulative effects of additional development in the Harbour.

Résumé

Le suivi saisonnier et annuel de l'endofaune et des contaminants sédimentaires a été effectué aux sites de référence reconnus pour leurs faibles concentrations en métaux et hydrocarbures aromatiques polycycliques (HAPs) dans le Port de Saint-Jean, au Nouveau-Brunswick, entre 2011 et 2013. Les objectifs de cette étude étaient d'établir une base de référence pouvant être utilisée dans le développement d'un programme de suivi à long terme dans le Port. L'abondance, la richesse spécifique, et la diversité de l'endofaune ont présenté des variations saisonnière, annuelle et spatiale et des assemblages spécifiques ont été identifié aux sites situés dans les portions intérieure et extérieure du Port. Tous les contaminants sédimentaires (19 métaux, 16 HAPs prioritaires) ont démontré très peu de variabilité entre sites, saisons ou années (typiquement < 5 fois plus) et seulement 2 métaux (arsenic et nickel) parmi les sites ont excédé les recommandations. Les résultats ont été utilisés pour concevoir un programme de suivi à long terme pouvant être utilisé pour évaluer les effets cumulatifs de développements additionnels dans le Port.

Introduction

Saint John Harbour is one of Canada's major ports and the largest natural harbour in New Brunswick and is situated at the mouth of the Saint John River where it enters the Bay of Fundy. The Harbour presents an estuarine environment influenced by strong tidal currents and with a seabed ranging from silt and mud to gravel and rock. Like many other coastal estuaries that have been important centres of human settlement, the Harbour has been subjected to a wide range of anthropogenic activities since the late 1800s. Saint John Harbour has major shipping traffic that is supported via a dredged channel; material from maintenance dredging is disposed of at the Black Point ocean disposal site, located in the Outer Harbour. Saint John Harbour also receives inputs of industrial effluents including those from oil refining, brewing, and pulp and paper production, as well as municipal effluents, from the surrounding concentration of major industries and urban development. Cumulative effects are likely to occur from the large number of human activities in estuaries like Saint John Harbour. However, monitoring programs and environmental impact assessments have traditionally focused on a single development and do not share common methodologies or a common framework, making it difficult to assess cumulative effects.

Researchers at the University of New Brunswick (UNB), in partnership with the Saint John Harbour – Environmental Monitoring Partnership (SJH-EMP; a consortium of industry, government and non-governmental organizations with interests in the Harbour), examined benthic invertebrate communities and sediment contaminants of the Inner and Outer Saint John Harbour. The goals were to provide the SJH-EMP with current baseline data on spatial and temporal variability in invertebrate communities and sediment contaminants and to integrate findings to assess relationships between infaunal organisms and sediment characteristics of the Harbour such as grain size, organic carbon, and the presence of contaminants. This research generated the information needed to develop a regional monitoring program, including an optimal sampling strategy (i.e., sites, times, and methods) and thresholds against which to assess changes. This will facilitate future monitoring of contaminants and biota and detection of cumulative effects of human activities in Saint John Harbour.

This report summarizes Phase 1 of the research on benthic infaunal invertebrate communities and sediment contaminants in the Saint John Harbour. This phase focused on characterizing spatial and temporal variability at reference sites from 2011-2013 (Years 1-2). Reference sites were identified on the basis of being removed from any known point sources of contaminants and on their low concentrations of contaminants measured in past studies (e.g. Parrott et al. 2002). The current results will form the baseline for comparison of data from Phase 2 (future publications), which focused on identifying potential "hotspots" of sediment contamination and whether benthic communities were considered to be impaired at those sites of potential concern (Years 2-3). The overall objective of this report is to summarize and identify the range of conditions at reference sites in Saint John Harbour.

BENTHIC COMMUNITIES

In the development of a cumulative effects monitoring program for Saint John Harbour, information about benthic marine invertebrates is crucial. Benthic invertebrates are ecologically important in marine habitats as they 1) are an important component of marine food webs, serving as a food source for many larger organisms, including commercially fished species, and 2) impact major ecological processes such as cycling of elements, water column processes, pollutant distribution and fate, and transport and stability of sediments (Snelgrove, 1997). Studies often use benthic infaunal invertebrates as indicators of anthropogenic impacts because they can respond relatively quickly to disturbances as most are small, have relatively short life spans, have limited mobility after settlement, can show measurable responses to environmental stress or change, and can be sampled quantitatively (Clarke and Warwick, 2001; Bacci, 2009). Distributions of infaunal organisms are also related to a variety of characteristics of their habitat (sediment characteristics, flow regime, food supply) (Snelgrove and Butman 1994) and habitat-specific invertebrate assemblages can be identified.

A number of studies have examined benthic infaunal communities in Saint John Harbour since the 1960's, particularly in the Outer Harbour, including an extensive survey in 2001 to monitor the impacts of dredged material disposal at the Black Point ocean disposal site (Envirosphere, 2002). This 2001 survey reported a characteristic benthic infaunal community throughout the Outer Harbour, with abundance and species richness increasing towards seaward areas and in proximity to the disposal site. The community consisted of deposit-feeding organisms, dominated by the small bivalve *Nucula proxima* and several species of polychaete worms (including *Tharyx* sp., *Nephtys incisa*, *Ninoe nigripes*, *Cossura longocirrata*, and *Ophelina acuminata*), but also included several species of suspension feeders (e.g., the clam *Arctica islandica* and the tunicate *Bostrichobranchus pilularis*) (Envirosphere, 2002). The community was considered to be similar to natural communities in other coastal areas of eastern North America with similar substrates and was not indicative of typical 'disturbed' communities. Little information exists on the infaunal communities of the Inner Saint John Harbour.

Although spatial characterization of benthic infaunal communities was extensive in some past studies, there is little information on their temporal variation. Additionally, sampling at individual sites has not been extensive enough to characterize the degree of small-scale spatial variability and sample sizes needed to detect significant changes at a given study site. Data from the 2011-2013 surveys in the present study will build upon the infaunal data which have been collected in previous studies. Specifically, the present research on benthic infaunal communities at reference sites will:

1. describe seasonal, annual, and spatial variability of infaunal communities at reference sites and their relationship to sediment characteristics;
2. examine the effect of sample size on ability to detect change in infaunal communities;

3. determine the taxonomic resolution of identification sufficient for detecting spatial and temporal variability in infaunal benthic invertebrate communities; and,
4. begin to define thresholds for a regional monitoring framework against which future changes can be assessed to determine if further monitoring or management is required.

CONTAMINANTS IN SEDIMENT

A number of studies on the Saint John Harbour over the past three decades have revealed higher concentrations of some metals in the Inner Harbour in comparison to the Outer Harbour and other sites in the Inner Bay of Fundy. These "hotspots" were likely related to localized anthropogenic activities. For example, an extensive survey by Ray and McKnight (1984) showed that mean concentrations of copper, lead, cadmium, and zinc in Courtenay Bay (Inner Harbour) were 1.2-2.8-times higher than all other sites in the Inner and Outer Harbour. Other metals (nickel, manganese, molybdenum, mercury) were not different across the >100 sites that were sampled in that study. Metal concentrations throughout the Harbour were low, but there was a trend of decreasing concentrations from Courtenay Bay in a seaward direction, indicating a small, but detectable anthropogenic input in the Courtenay Bay area. Inner Harbour sediments were measured again in 1992 (31 stations) (Tay et al., 1997) and mean concentrations of copper, lead, mercury, and zinc were similar to previous results, but cadmium concentrations were found to be lower than the previous study. Monitoring of the Harbour in 2001 showed that some of the highest concentrations of chromium, copper, nickel, lead, and zinc (21, 43, 20, 43, and 227 mg/kg dw, respectively) in Inner Harbour sediments were located in shallow waters near East Saint John, an area that receives sediment from the Little River which flows past industrialized sites. Elevated concentrations of these metals also occurred near the shipyards at the mouth of the Saint John River and south of Partridge Island (Parrott et al., 2002). However, metal concentrations of most sediment sampled throughout the Harbour were below Canadian Council of Ministers of the Environment (CCME) Interim Sediment Quality Guidelines (ISQGs) for arsenic, chromium, copper, lead, and zinc (7.2, 52, 19, 30, and 124 mg/kg dw, respectively; CCME, 1999), with the exception of only 1 or 2 samples. More recent analyses of a limited number of sites showed that sediment concentrations of aluminum, copper, manganese, nickel, and zinc at two locations (Red Head and Hazen Creek) in the Inner Harbour were up to 2-times higher compared to two sites (Ducks Cove and Saints Rest) further removed from human activities, while concentrations of cadmium and lead were similar between all four sites (Doyle et al., 2011). Some of the differences in concentrations among studies may be related to differences in analytical techniques.

Some organic contaminants have also been measured in sediments from the Saint John Harbour. Polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) were measured in sediments collected from Inner and Outer Harbour sites in 1992 (Tay et al., 1997). Most stations (n = 21/31 Inner Harbour and 17/18 Outer Harbour) had below detectable concentrations for PCBs (<10 µg/kg dw total Arochlor), some sites had measurable PCB concentrations (19-73 µg/kg) and two samples exceeded Disposal at Sea guidelines of 100 µg/kg dw (Canada Gazette, 2001; i.e., 134

and 348 µg/kg). Disposal at Sea guidelines for total PAHs (2.5 mg/kg dw; Canada Gazette, 2001) were also exceeded at 6 sites in the Inner Harbour, with concentrations ranging from 0.5 to 19 mg/kg dw. In a 2001 survey, concentrations of PCBs in Outer Harbour sediments ranged from <10 µg/kg dw at most sites (n = 55/64) to 35 µg/kg dw and PAH concentrations ranged from <0.05 mg/kg dw at half of the sites (n = 31/64) to 1.6 mg/kg (Land and Sea 2001). More recent data for these contaminants in the Harbour are relatively sparse or remain unreported.

Despite the range of studies that have been done on the Saint John Harbour, little current information exists on sediment contaminants and none have generated the information needed to identify appropriate reference sites and the degree of natural variation at these sites that are critical for setting thresholds and triggers for a regional monitoring framework. To address this, the present research on contaminants in sediment at reference sites in the Harbour will:

1. examine spatial and temporal (seasonal and annual) variability of a suite of sediment contaminants (metals, PAHs and PCBs (spatial only));
2. establish reference, baseline concentrations; and,
3. refine the critical effects size needed to define a warning level against which future changes can be assessed and further monitoring or management is required.

Materials and Methods

LONG TERM REFERENCE SITES

Existing data from studies conducted in Saint John Harbour (e.g., Parrott et al., 2002; Envirosphere, 2003) and consultations with the SJH-EMP were used to choose reference sites for sampling in Year 1. Six reference sites were chosen for the first year of grab sampling (2011-2012) - three in the Inner Saint John Harbour and three in the Outer Saint John Harbour (Figure 1, Table 1). For the purpose of this report, the Inner Harbour is defined as the area north of Black Point (eastern shore) and Sheldon Point (western shore); none of the reference sites were located in the very innermost part of the Inner Harbour. The references sites were selected based on:

- presence of soft substrate (as defined with known maps of the Harbour bottom);
- being removed from any known point sources of contaminants (least developed sites); and
- known, low concentrations of metals, PCBs, and PAHs.

Sampling was conducted on the following timeline to examine seasonal (Year 1) and interannual variability (Years 1-2):

Year 1: August 2011, October 2011, April 2012, and June 2012
Year 2: October 2012 and June 2013

In the first sampling event, grabs at one of the sites selected in the Outer Harbour (Site 05: 45°11.529N, 66°05.735W; data not included in report) did not capture much sediment and a different site (Site 13; Figure 1; Table 1) was selected for later sampling events.

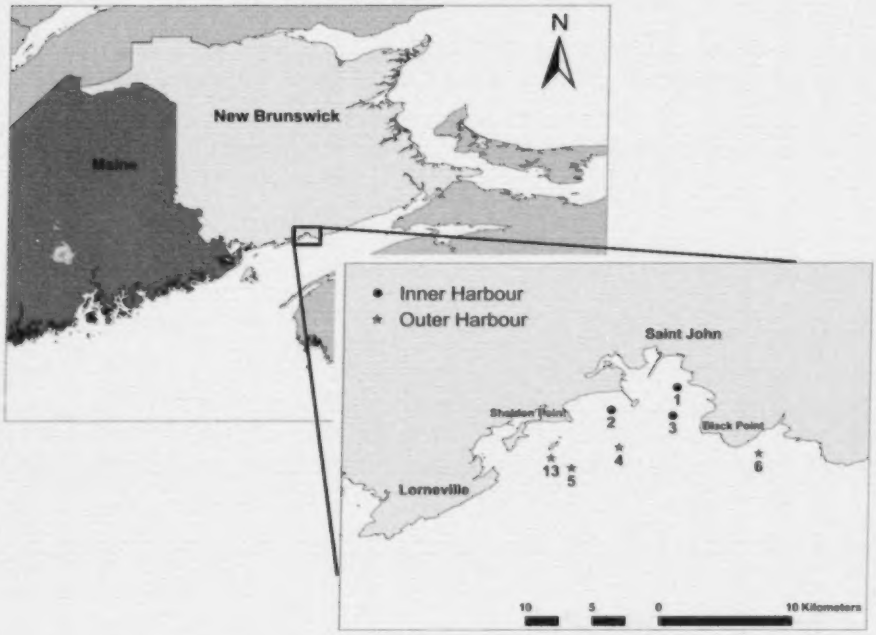

Figure 1. Locations of reference sites in the Inner and Outer Saint John Harbour, New Brunswick, 2011-2013.

Table 1. Locations and descriptions of reference sites in the Inner and Outer Saint John Harbour, New Brunswick, 2011-2013, including depth below mean low water (MLW).

Site	# sample events	GPS coordinates (WGS 84)	Depth below MLW (m)	Description
Inner Harbour				
01	6	45°14.957N, 66°01.506W	3.6	South of sewage outfall, near Red Head. Fine sediment with patches of sand, presence of pebble and shell hash.
02	6	45°13.989N, 66°04.160W	7.7	Southwest of Partridge Island. Fine sediment, slightly anoxic.
03	6	45°13.748N, 66°01.670W	8.0	North of dredging disposal site near Black Point. Fine sediment, presence of organic debris.
Outer Harbour				
04	6	45°12.412N, 66°03.815W	12.6	Midway between Manawagonish Island and the dredging disposal site. Fine to sandy sediment.
06	6	45°12.151N, 65°58.172W	37.5	Southeast of Canaport LNG ship loading area. Dense fine sediment, presence of pebble, cobble, organic debris and shell hash.
13	5[a]	45°11.958N, 66°06.572W	12.6	Southeast of Manawagonish Island. Fine sediment, usually anoxic, presence of shell hash and organic debris.

[a] Site 13 replaced Site 05 in October 2011 due to lack of suitable substrate for sampling

SAMPLE SIZE REQUIREMENTS

Sampling for benthic invertebrates, sediment characteristics and contaminants was done concurrently so that the relationships between them could be examined; however, in some cases the number of replicates per site varied between the approaches. For both contaminants and infaunal invertebrates, ten replicates were originally taken at each site in August 2011 (except Site 05).

Sediment chemistry sampling: Power analyses of the most variable sediment chemistry results from the initial samples indicated that a minimum of 5 replicate samples were required to achieve 80% power with an alpha of 0.05 and an effects size of 2 standard deviations (SD).

For contaminants, 6-10 replicates per site were collected in October 2011, and only 5 replicates per site were taken thereafter. For the benthic invertebrate communities, time constraints and sampling difficulties limited the number of samples collected at some sites on some dates. As a result, 6 replicates were collected at each site in October

2011 (but 5 at Site 01), 10 replicates at each in April 2012 (but 5 at Site 01 and 8 at Site 06) and June 2012, and 8 replicates at each site in October 2012 and June 2013 (Appendix B, Table B-2). Strong tidal currents and waves were the main reason for the reduced number of replicate samples as it was difficult to successfully deploy the grab (i.e., sampler hit the bottom at an angle and did not penetrate or capture sediment).

FIELD SAMPLING PROTOCOL

A ~0.1 m^2 Smith McIntyre grab (SMG) sampler (Smith and McIntyre, 1954; Wildish and Wilson, 1976) attached by a cable to the winch of a 50' converted offshore lobster boat was used to collect quantitative samples of surface sediment for physical, chemical, and infaunal analysis (Appendix A; Figure A-1). The SMG grab was lowered vertically from the stationary boat to collect sediment. After the grab was triggered, it was slowly pulled up onto the deck of the boat and placed on the hopper, and penetration depth and sample width were measured.

Due to the large tides in the Bay of Fundy and the Saint John River flowing into the Harbour, currents in the Harbour are strong and make grab sampling difficult. Best results were obtained when Inner Harbour sites were sampled during or just after high tide, as currents in this portion of the Harbour are at their minimum 2 hours after high tide (Jeff Melanson, UNB Ocean Mapping Group, pers. comm.). Due to their greater depth (Table 1), Outer Harbour sites were sampled at low tide to minimize water depth.

To obtain representative benthic samples, sediment penetration depth must be at least 5 cm (Stubbs et al., 1987). For Saint John Harbour sediment - composed mostly of fine sand, silt, and clay - a penetration depth of 7 to 9 cm was usually obtained, with occasional samples reaching a depth of up to 14 cm. The depth of penetration for each grab was determined by insertion of a ruler vertically along the grab midline. The sediment in the grab was separated into two halves (Appendix A; Figure A-2). One side of the grab was sampled for physicochemical analysis and the other side was used for infaunal analysis. Acceptability of the grab samples was based upon a minimum depth of penetration of 5 cm. Sampling was repeated until the sufficient number of acceptable grab samples was obtained; however, in some cases (<2% of samples) samples less than 5 cm in depth were accepted due to time constraints and difficulty penetrating the sediment.

For the infaunal half of the grab, the volume of sediment sampled for each replicate was estimated using a MatLab (v. R2011a) program (written by P. Riley of the UNB Dept. of Engineering). An arc with a 23-cm radius was used to closely match the curvature of the sampler. The surface area was limited by the maximum jaw width (27.9 cm) of the sampler and was estimated to be 321 cm^2. Volume was calculated using the arc of the sampler, and measured width and depth of the sample. For bulging samples (10 to 14 cm deep), the arc of the bulging surface was modelled using a parabolic equation to estimate and add the additional volume above that of a flat upper surface. The volume of sediment sampled for infauna ranged from approximately 0.5 L to 4 L.

At each sampling site and for each replicate, GPS coordinates and observations were recorded. When samples appeared anoxic (based on colour change with sediment depth and sulfidic smell) and contained considerable debris, a description of the sediment was noted (Appendix B; Table B-1), including:

- Texture: shell hash, cobble, pebble, gravel, sand, or mud (silt and/or clay);
- General sediment colours (e.g., black, green, brown, red, yellow) and colour change with depth as a possible indicator of redox state;
- Smell: none, sulfidic (H_2S), or humic (musty, organic odor);
- Other (e.g., occurrence of concretions, organic debris, epifaunal organisms, etc.).

Slightly less than half of the sediment (infaunal portion) in the grab was then scooped out with a trowel and sieved through a 0.5-mm mesh, large, plastic sieve in a tub filled with seawater. Organisms were then gently rinsed from the sieve with seawater from a squirt bottle, and placed directly into labeled, 8 or 16 oz. polypropylene jars. Organisms and any remaining sediment (>0.5 mm) were immediately preserved with ethanol (95% v/v purity).

A subsample (top 5 cm) from the remaining portion of the grab (physicochemical portion) was collected using a new pre-cleaned plastic corer at each site and placed into labeled, 250 mL pre-cleaned glass amber containers (purchased certified pre-cleaned for semivolatile, pesticide/PCB, and metal analyses; Fisher Scientific, Canada). The corer was labelled with a 5 cm depth mark and was 6.4 cm in diameter, which gave a typical sample volume of ~160 mL. In cases where grab samples were less than 5 cm in depth (<2% of samples), the same volume of sediment was collected from a larger surface area of the grab for the physicochemical analyses. In Oct. 2011 when there were difficulties getting the grab to penetrate well at Sites 01, 04, and 06, samples from some grabs were collected for physiochemical analyses but not benthic invertebrates due to insufficient sediment for the invertebrate analysis. All sediment samples were kept on ice in coolers until they were brought to the laboratory at UNB-Saint John. Samples for sediment chemistry were then frozen until needed for analysis.

PROCESSING AND ANALYSIS OF BENTHIC INVERTEBRATE SAMPLES

SAMPLE PROCESSING AND IDENTIFICATION

All benthic invertebrate samples collected in August 2011 (n = 10 replicates per site) were processed and thereafter, a subset of preserved infauna samples collected on other dates were processed (Appendix B; Table B-2). Benthic samples from sediment grabs with less than 5 cm sediment depth typically were not processed unless there were fewer than 5 replicates with sediment depth greater than 5 cm (see below for details).

Preserved benthic samples were processed by sieving (0.5-mm mesh, stainless steel sieve) them gently with freshwater to remove any remaining fine sediment. Pebbles, cobbles, broken shell pieces, and debris were removed and the sample portion greater than 0.5 mm was poured into small glass petri dishes and covered with 95% ethanol to

prevent desiccation during sorting and identification. Samples were examined under a dissecting microscope using a magnification between 10x and 100x. A compound microscope was also used to look at finer features necessary for the identification of most organisms. Due to some damage during the sieving process, many organisms (mostly polychaetes) were found in sections. To avoid overestimating organism density, only head portions were counted for the groups that were found in larger numbers (e.g., *Cossura longocirrata*). For less common species, all heads and tails were gathered and the greater of the two numbers was recorded. Bryozoans and foraminiferans were not included in the count as they were most likely drifting dead organisms at the time of sampling.

All organisms were identified to the species level whenever possible, using at least two peer-reviewed sources as guides. Each new organism identified was catalogued (in a glass vial with 95% ethanol) and pictures were taken. This catalogue was sent to the Atlantic Reference Centre (St. Andrews, NB) for confirmation of species identification. Some organisms could not be identified to the species level because of damage or missing features. These organisms were grouped into their genus or family or even larger groups like phylum. Data in this study uses the highest taxonomic resolution possible, but some groups are better described than others (species versus family). For lower taxonomic resolution groups (e.g., family), the organisms were separated and added to the individuals already identified to species within that group according to percentage of each species within the group. This was done to avoid possible duplication of the number of taxa studied (see Appendix B; Table B-3 for species list). Some species were merged and presented as families or genera if there was uncertainty about the identification of each species (e.g., *Eudorella* spp.). A few individuals were also eliminated from the database because damage during sieving or handling resulted in a lack of characteristics necessary for identification to at least the family level (e.g., missing shells, heads, or tails). The World Register of Marine Species (WoRMS, 2014) and the Integrated Taxonomic Information System (ITIS) online databases were used to verify and update each taxonomic entry (i.e., authoritative taxonomic names).

Data on species abundance (# individuals/m^2) and occurrence were entered into a database created for this project, which could later be queried to generate spreadsheets for input into statistical packages.

DATA ANALYSIS

Benthic community data were analysed from 10 replicates per site for August 2011 (except Site 13 not sampled on this date) and 5 replicates per site for all dates thereafter. Data from samples with a 4 to 5 cm sediment depth were only included when necessary to achieve a minimum of 5 replicates (1 sample at Site 01 in Oct. 2011, and 2 samples at Site 01 and 1 at Site 03 in April 2012; Appendix B; Table B-2). Species abundance was normalized to the 'expected' surface area of sediment sampled for invertebrates (27.9 cm x 11.5 cm = 321 cm^2), which was less than half of the measured opening of the grab sampler. Species abundance per volume of the grab

was not used because most of the species were found in the top few cm of sediment. Data were grouped by major taxonomic group and averaged across replicates and sampling dates for general discussion of species composition of benthic samples. The Shannon diversity index (H') was calculated as: $H' = \sum_i p_i \times log(p_i)$, where p_i is the proportion of the total individuals from the i^{th} species.

Both seasonal and interannual variability have the potential to influence trends in benthic communities within the Saint John Harbour. Therefore, to evaluate this potential variability at reference sites in the present study, total organism abundance, species richness, and Shannon diversity index (H') were compared across sites and sampling dates. To examine seasonal variation of organism abundance, species richness, and diversity (H') at reference sites, data were compared between the four sampling dates in Year 1 (August 2011, October 2011, April 2012, and June 2012). To examine interannual variation, data were compared between October 2011 and October 2012 and between June 2012 and June 2013.

To determine whether there was an interaction between sampling date and site on mean organism abundance, species richness, and diversity (H') at these reference sites, a two-way analysis of variance (ANOVA) was conducted with all Inner and Outer Harbour sites. Factors (date, site) and the interaction (date x site) were considered significant at an alpha of 0.05. The Kolmogorov-Smirnov test of normality and Levene's Median test of equal variance were used prior to all ANOVAs. Data were transformed using various methods (i.e., log, squared) to meet the assumption of normality and equal variance, where possible. The Holm-Sidak method was used for all pairwise multiple comparisons (SigmaStat 3.5). Since Site 13 was not sampled in August 2011, this created an unbalanced design for the two-way ANOVA; therefore the analysis was run twice, once excluding all August 2011 and once excluding Site 13 data.

Multivariate analyses of the benthic invertebrate community were done using PRIMER 6.0. Differences in assemblages among sites and dates were visually represented using non-parametric multidimensional scaling (MDS) plots based on Bray-Curtis similarity matrices. Prior to creation of the similarity matrices, abundance data were square-root transformed to down-weight the importance of numerically dominant animals. The main patterns were unchanged when data were analysed using untransformed data or following log or presence/absence transformations (data not presented). Following these multivariate graphical representations, two-way permutational multivariate analysis of variance (PERMANOVA) was used to assess the effect of site and sampling date on the invertebrate assemblages in the grab samples. As for the univariate analyses described above, data analyses for the seasonal comparisons were run twice, once excluding August 2011 and once excluding Site 13 data.

Linear models were used to examine relationships between mean values of organism abundance, species richness, or diversity (H') for each combination of site and sampling date (n=35 data points) and mean sediment % moisture, % total organic carbon, % loss

on ignition at 950°C, and average grain size (*Mz*). The best fitting model out of all possible combinations of the sediment parameters and a null model (intercept only) was determined using the Akaike Information Criterion (AICc).

The PRIMER Biota-Environmental matching and Stepwise (BEST) procedure (Clarke and Warwick, 2001) was used to determine the highest correlation between spatial and temporal patterns of square-root transformed infaunal abundance data and combinations of the following sediment parameters: % moisture, % total organic carbon, % loss on ignition at 950°C, and average grain size (*Mz*). The BEST procedure estimated Spearman correlation (ρ_s) values between Bray-Curtis community similarity matrices and the Euclidean distance similarity matrices derived from different subsets of the normalized abiotic data for the same grab samples.

To determine how altering the level of taxonomic resolution would affect the results of the multivariate analyses, abundances were aggregated to the levels of genus, family, suborder, order, infraclass and class and separate Bray-Curtis similarity matrices were obtained for untransformed, square-root transformed, log-transformed, and presence/absence transformed abundance data for each of these different resolutions. Taxonomic sufficiency was tested by calculating Spearman rank correlations (ρ_s) between species and lower taxonomic resolution similarity matrices using the RELATE procedure in PRIMER (Clarke and Warwick 2001).

Since some infaunal invertebrate species were spatially clumped at a site, an index of dispersion was calculated to determine which species were less spatially clustered within a site and might therefore have a lower variance for future monitoring. In PRIMER 6, the index of dispersion (D), which corresponds to a "clumping" measure, was calculated as: $D = \sigma^2/\mu$, where σ^2 is the variance and μ the mean (Clarke et al., 2006). Out of the 149 species, 5 relatively abundant and well-distributed species ($D < 3$) were selected as potentially good discriminating species and power analyses were done for these individual species.

PHYSICAL/CHEMICAL ANALYSES OF SEDIMENT

Frozen sediment samples were thawed prior to analyses and macroinvertebrates or debris (pieces of wood, fibres or plastic) were manually removed. The wet sample was homogenized and aliquots (see Table 2) were removed for determination of loss on ignition (LOI) and % moisture. The remainder of the sample was freeze-dried for a minimum of three days and then homogenized using a dried, acid washed glass mortar and pestle. Aliquots of the dried sample were removed for determination of grain size, elements, total mercury (Hg), PAHs, and PCBs. Sample requirements and methods for the different physicochemical analyses are summarized in Table 2 and described in detail in subsequent sections.

Table 2. Summary of physicochemical analyses of sediment samples.

Test	Mass of sample	Unit Reported	Method Used
$LOI_{550/950}$	20 g wet	%	Gravimetric
TOC	Calculated from LOI_{550}	%	Calculated from linear regression % TOC = (0.255 x % LOI_{550}) - 0. 111, R^2 = 0.882
Moisture	15 g wet	%	Gravimetric
Grain Size	20 g dry	%	Gravimetric
Elemental (Metals)	0.5 g dry	mg/kg dw	Digestion and ICP-OES quantification based on US EPA 3051, 200.7, and 6010C methods
Total Hg	0.03 g dry	µg/kg dw	DMA-80 based on US EPA 7473 methods
PAHs	≥10 g dry	mg/kg dw	ASE extraction, GPC cleanup and GC/MS quantification based on US EPA 3545, 3640A and 8270C methods
PCBs	≥10 g dry	µg/kg dw	ASE extraction, GPC and Florisil cleanup and GC/ECD quantification based on US EPA 3545, 3640A, 3620C, and 8082 methods

MOISTURE CONTENT

An empty container was weighed (Sartorius CP323S balance) and then reweighed once ~15 g of homogenized, wet sample was added. The container was covered with a Kimwipe and then placed in the freeze dryer (Labconco FreezeZone[12]) for a minimum of three days. The container was re-weighed and the percent moistures were calculated as follows:

$$\%\ Moisture = \left(1 - \left[\frac{(weight\ of\ container + dry\ sample) - weight\ of\ container}{(weight\ of\ container + wet\ sample) - weight\ of\ container}\right]\right) x\ 100\%$$

GRAIN SIZE

Approximately 20 g of homogenized, dried sediment was weighed into a tared, clean 150 mL beaker. Using a series of sieves stacked from largest to smallest mesh size (4, 1, 0.500, 0.250, 0.125, and 0.063 mm) with a piece of paper under the last sieve to catch the finest grain fraction, the sample was dumped into the top sieve and the stack was manually shaken for 10 minutes. The empty beaker was re-weighed to determine the actual weight of the sample used. The contents of the 4-mm sieve were carefully transferred to a piece of paper and then into a tared beaker and the mass recorded. This was repeated for each of the remaining sieves and the percent of each grain size fraction was determined gravimetrically as follows:

$$\%\ Grain\ size\ fraction = \frac{weight\ of\ sediment\ fraction\ in\ sieve}{total\ weight\ of\ sample} x\ 100\%$$

Grain size fractions were classified as follows based on the Wentworth scale are listed in Table 3.

Table 3: Grain size Wentworth size class and reported categories.

Grain size (mm)	Wentworth size class	Reported category
>4	Pebble	Gravel
1 to <4	Very coarse sand and granule	
0.5 to <1	Coarse sand	Coarse sand
0.250 to <0.5	Medium sand	Fine and medium sand
0.125 to <0.250	Fine sand	
0.063 to <0.125	Very fine sand	Silt and clay
<0.063	Silt and clay	

Average grain size (*Mz*) was determined as: $Mz\ (mm) = \sum(f_i m_i)/100$, where m_i is the size of grade *i* (i.e., 4, 2, 1, 0.5, 0.25, 0.125, 0.063 mm) and f_i is its percentage.

LOSS ON IGNITION AND TOTAL ORGANIC CARBON

Loss on ignition (LOI), which is a measure of all organic matter, is a common alternative to the dry combustion measurement of total organic carbon (TOC) due to the reduced cost and labour for LOI and the ability to estimate TOC based on a relationship between these two parameters.

Approximately 20 g of homogenized, wet sample was weighed into a tared, clean, pre-weighed ceramic dish and the wet weight of the sample recorded. The sample was dried for 16 hours at 105°C in an oven (Fisher Scientific Isotemp), cooled in a desiccator and then weighed. The sample was then heated to 550°C (Barnstead Thermolyne 30400 Furnace) and held at that temperature for 3.5 hours, cooled, and then weighed. Then the sample was heated to 950°C and held for 1.5 hours, cooled, and weighed. Estimates of loss on ignition (LOI) at 550 and 950°C were determined gravimetrically as follows:

Dry weight (DW) = (weight of dish + dry sample at specific temperature) – weight of dish

$$\%LOI_{550} = \frac{(DW_{105} - DW_{550})}{DW_{105}} x\,100\% \qquad \%LOI_{950} = \frac{(DW_{550} - DW_{950})}{DW_{105}} x\,100\%$$

Total organic carbon was calculated based on the results of LOI. Initially, 20 samples were sent to Research Productivity Council (RPC; Fredericton, NB) for measurement of TOC using a LECO combustion/infrared method (based on Strobel et. al., 1995). The TOC content from RPC and the LOI_{550} content from UNB were fit with a linear regression model in the form TOC = slope x LOI ± intercept, which was not forced through the origin. The resulting equation was used to convert the % LOI_{550} to % TOC (± SE for slope and intercept).

$\%\ TOC = (0.255 \pm 0.022\ x\ \%\ LOI_{550}) - 0.111 \pm 0.073$, $R^2 = 0.882$

The Min and Max TOC values used in the regression were 0.4 and 1.3% respectively. A total 5.2% of the samples fell outside the regression range (22/423 samples). As a quality control for the higher TOC samples, we determined the LOI of certified reference material (CRM) 1941b (n=2, target of 2.99 ± 0.24% organic content) and calculated the TOC using the same regression shown above. The TOC was determined to be 2.17% and 2.44% TOC (average recovery of 77.0% based on the CRM target value).

ELEMENTS

Sample digestion and analysis of metals followed a test method based on US Environmental Protection Agency (US EPA) standard testing protocols 3051A (US EPA, 2007a), 200.7 (US EPA, 1994a), and 6010C (US EPA, 1998a). A 0.5 g aliquot of homogenized, dried sample was digested using a microwave digestion (CEM Mars 5) and 10 mL of metal grade nitric acid (Fisher Scientific, Canada). (This is considered to be a soft digestion that provides information on the more bioavailable/leachable fraction of metals rather than a vigorous digestion (using hydrofluoric acid) that extracts all metals in the sample.) Then 40 mL of Milli-Q water and known standardized amount of Yittrium (Y) (SCP Science, QC) was added as an internal standard after the digestion process. Samples were filtered using Millex syringe filters (0.45 µm) and disposable syringes with polyethylene barrels and polypropylene plungers (Fisher Scientific) into polypropylene test tubes (Fisher Scientific) for analysis. The following 22 elements were quantified using an inductively coupled plasma-optical emissions spectrophotometer (ICP-OES, iCAP 6500 Duo, Thermo Fisher Scientific) using an internal standard calibration method. Limit of quantification (LOQ; see below) and wavelengths used for quantification are listed in Table 4.

Table 4: Summary of LOQ and wavelength for individual elements reported.

Element	Symbol	LOQ (mg/kg dw)	Wavelength (λ)
aluminum	Al	<2.7	396.1
arsenic	As	<1.6	189.0
cadmium	Cd	<0.08	228.8, 214.4
chromium	Cr	<0.12	267.7
cobalt	Co	<0.15	228.6
copper	Cu	<0.19	324.7
iron	Fe	<0.64	259.9
lanthanum	La	<1.0	333.7
lead	Pb	<0.77	220.3
magnesium	Mg	<4.3	279.0
manganese	Mn	<0.03	257.6
nickel	Ni	<0.13	221.6
phosphorus	P	<0.67	177.4
rubidium	Rb	<0.86	780.0
selenium	Se	<1.1	196.0
silver	Ag	<0.22	328.0

Table 4 (continued)

Element	Symbol	LOQ (mg/kg dw)	Wavelength (λ)
strontium	Sr	<0.004	407.7
sulphur	S	<1.1	180.7
thallium	Tl	<0.55	190.8
uranium	U	<6.4	409.0
vanadium	V	<0.15	292.4
zinc	Zn	<0.04	202.5, 206.2, 213.8

Quality assurance/quality control (QA/QC) procedures included the following: each batch of 11 samples included a method blank (MB), CRM [National Institute of Standards & Technology (NIST) Standard Reference Material (SRM) 2702 Inorganics in Marine Sediment], and sample duplicate (see Table K-1 for recoveries). The MB consisted of Ottawa sand (Fisher Scientific, Ottawa, ON) which was run through the entire testing process. The target MB value was equal to or less than the LOQ. For instances where the MB was greater than the LOQ, the LOQ was increased to the level found in the blank. CRM and calibration check results were reported as percent recovery based on the certificate's certified and calculated target values. The duplicate samples were reported as relative percent difference. Instrument blanks and calibration checks were routinely done throughout the analysis. All standards (SCP Science, QC), calibration checks (SCP Science, QC), and reference materials were certified with a certificate of analysis. Instrument detection limits (IDL) were determined by running 20 repeats of a blank (IDL = $average_{blanks} + 3 \times SD_{blanks}$; based on US EPA 200.7). The LOQs were determined to be 5 times the IDL (Montaser and Golightly, 1992).

TOTAL MERCURY

Sample preparation and analysis of total mercury followed a test method based on US EPA standard testing protocol 7473 (US EPA, 1998b). A 0.03 g aliquot of homogenized, dried sample was run on a direct mercury analyzer (Milestone DMA-80). Quality assurance/quality control procedures included the following. Each batch of 10 samples included an instrument blank, method blank, CRM (NIST SRM 2702 Inorganics in Marine Sediment; see Table K-1 for recoveries), calibration standard checks, and sample duplicate. The QA/QC procedures for the MB, CRMs, standard checks and sample duplicates followed those for analysis of other metals. All standards (Ultra Scientific, N. Kingstown, RI, USA), calibration checks, and reference materials were certified with a certificate of analysis. The limit of detection (LOD) was determined by averaging all the method blanks run in the batch and adding 3 times the SD of the method blanks (LOD 2.8-4.9 µg/kg dw total Hg).

POLYCYCLIC AROMATIC HYDROCARBONS

Sample extraction and analysis of PAHs followed a test method based on US EPA standard testing protocols 3545A (US EPA, 2007b), 3640A (US EPA, 1994b), and 8270C (US EPA, 1996c). A minimum 10 g aliquot of homogenized, dried sample was extracted using an Accelerated Solvent Extractor (Dionex ASE 300) with distilled in glass (DIG) grade, 50:50 dichloromethane (DCM):hexane (Caledon Laboratories, Georgetown, ON). Extracted samples were concentrated to 6 mL of 50:50 DCM:Hexane using a Büchi rotavapor (R-200) and nitrogen evaporator (N-EVAPTM112, Organomation Associates Inc.). Samples were run through a gel permeation column (J2 Scientific Automated Gel Permeation System) using 50:50 DCM:hexane to remove heavier contaminant that may interfere with the quantification of PAHs. The sample was then concentrated into 1.0 mL isooctane (pesticide grade, Fisher Scientific) using the same techniques mentioned above. A known standardized amount of internal standard solution (naphthalene-d8, acenaphthene-d10, phenanthrene-d10, chrysene-d12 and perylene-d12) was added to each sample prior to quantification. The concentrated extracts were run on a gas chromatograph-mass spectrometer (Agilent 6890/5975B GC-MS) and quantified using an internal standard calibration and single ion monitoring mode.

Quality assurance/quality control procedures included the following. Each batch of 8 samples included a MB, MS, CRM (NIST SRM 1941b Organics in Marine Sediments; see Table K-1 for recoveries), and sample duplicate. Individual sample recoveries were verified by adding a known amount of three surrogates (nitrobenzene-d5, 2-fluorobiphenyl, p-Terphenyl; certified standards, SPEX Certiprep, Metuchen, NJ, USA) to each sample, MB, MS, CRM, and sample duplicate prior to the extraction. The surrogates were reported as percent recovery based on the calculated target concentration. In addition, instrument performance was verified by running tune check standards, and calibration check standards for both the target and surrogate compounds. All calibration standards, calibration check standards, tune standards, surrogates standards, and internal standards were certified (SPEX Certiprep, Metuchen, NJ, USA). Method detection limits (MDLs) were determined by running 8 low level spike samples (5x higher than the expected MDL) through the entire process. The t-value (n = 8, 95%) was multiplied by the standard deviation of the 8 runs to determine the MDL for each PAH. The MDL of the total PAHs was determined by taking the square root of the sum of squares of the individual PAH MDLs.

Analyses included quantification of 16 PAHs using the quantification ions listed in Table 5. The MDL was <0.01 mg/kg dw for individual PAHs. For the purpose of this report, data were summed and reported as total PAHs (MDL <0.04 mg/kg).

Table 5: Quantification ion used for quantifying the individual PAHs.

PAH	Quantification Ion
acenaphthene	153
acenaphthylene	152
anthracene	178
benzo[a]anthracene	228
benzo[a]pyrene	252
benzo[b]fluoranthene	252
benzo[k]fluoranthene	252
benzo[g,h,i]perylene	276
dibenzo[a,h]anthracene	278
chrysene	228
fluoranthene	202
fluorene	166
indeno[1,2,3-cd]pyrene	276
naphthalene	128
phenanthrene	178
pyrene	202

POLYCHLORINATED BIPHENYLS

PCBs were only measured in the October 2011 samples of the present study. Sample extraction and analysis of PCBs followed a test method based on US EPA standard testing protocols 3545A (US EPA, 2007b), 3660B (US EPA, 1996a), 3640A (US EPA, 1994b), and 8082 (US EPA, 1996b). A minimum 10 g aliquot of homogenized, dried sample was spiked with a surrogate solution containing PCB 30 and PCB 204 (Accustandard, New Haven, CT, USA) and then extracted using an ASE 300 with DIG grade, 50:50 DCM:hexane (Caledon Laboratories, Georgetown, ON. Sulphur was removed using activated copper. Extracted samples were concentrated to 6.0 mL of 50:50 DCM:Hexane using a Büchi rotavapor (R-200) and nitrogen evaporator (N-EVAPTM112, Organomation Associates Inc.) and were run through a gel permeation column (J2 Scientific Automated Gel Permeation System) to remove contaminants that may interfere with the quantification of PCBs. Samples were re-concentrated to 1.0 mL of isooctane. Each sample was spiked with a known amount of internal standard containing PCB 103 and PCB 198 (AccuStandard, New Haven, CT, USA). The final extracts were run on a gas chromatograph-electron capture detector (Agilent 6890 GC-ECD) and quantified using an internal standard calibration.

Quality assurance/quality control procedures included the following. Each batch of 8 samples included a MB, MS, CRM (NIST SRM 1941b Organics in Marine Sediments; see Table K-1 for recoveries), and sample duplicate. The QA/QC procedures for the MB, CRMs, standard checks and sample duplicates followed those listed for PAH

analysis. MDLs were determined by running 8 low level spike samples (5x higher than the expected MDL) through the entire process. The t-value (n = 8, 95%) was multiplied by the standard deviation of the 8 runs to determine the MDL for each PCB congener. The reporting limit (RL) for PCBs was based on the amount of the lowest calibration standard and determined to be 0.12 µg/kg dw for each individual congener, when two congeners co-eluted the RL was 0.24 µg/kg. The MDLs were equal to or less than the RL. All calibration standards, calibration check standards, surrogates standards, and internal standards were certified (AccuStandard, New Haven, CT, USA). Tune standards were also certified (SPEX Certiprep, Metuchen, NJ, USA).

Analyses included quantification of the following 88 individual PCBs congeners, some of which co-eluted. For the purpose of this report, congener data were summed and reported as total PCBs (RL <2.9 to <3.7 µg/kg dw).

PCB 4/10	PCB 31	PCB 74	PCB 119	PCB 172
PCB 5	PCB 33/53	PCB 76	PCB 123/149	PCB 174
PCB 6	PCB 37/42	PCB 77/110	PCB 126/178	PCB 180
PCB 8	PCB 44	PCB 81/87	PCB 128/167	PCB 187
PCB 9/7	PCB 45	PCB 83	PCB 131	PCB 190
PCB 12/13	PCB 47	PCB 85	PCB 132/105	PCB 194
PCB 17/15	PCB 48	PCB 91	PCB 135/144	PCB 199
PCB 16/32	PCB 49	PCB 92/84	PCB 146	PCB 201
PCB 18	PCB 52	PCB 97	PCB 151	PCB 202
PCB 19	PCB 56/60	PCB 99	PCB 153	PCB 204[a]
PCB 22	PCB 64/41	PCB 100	PCB 163/138	PCB 205
PCB 26	PCB 66/95	PCB 101/89	PCB 169	PCB 206
PCB 28	PCB 70	PCB 114	PCB 170	PCB 207
PCB 30[a]	PCB 71	PCB 118	PCB 171/156	

[a] spiked surrogates

DATA ANALYSIS

Analytical results for chemical parameters that were less than the corresponding detection limits (i.e., < LOD, MDL, or RL; % of samples reported in Table 6) were replaced with a random value below the detection limit. Overall summary statistics were calculated based on all samples (i.e., all replicates for all sites on all sampling dates) for general comparison to sediment quality guidelines. Summary statistics were also calculated for each sampling date (5-10 samples/date) at individual sites in the Inner and Outer Harbour.

Both seasonal and interannual variations have the potential to influence long-term trends in sediment contaminant concentrations within Saint John Harbour. Therefore, to evaluate this potential variability at references sites in the present study, arsenic, lead, zinc, and total PAHs were selected as representative chemical parameters because these compounds represent both metal and organic groups, and have ISQGs and

considerable historical data. To examine seasonal variation of sediment concentrations at reference sites, data were compared between the four sampling dates in Year 1 (August 2011, October 2011, April 2012, and June 2012). To examine interannual variation data were compared between October 2011 and October 2012 and between June 2012 and June 2013. It should be noted that some of the within-site differences between seasons and years may also be due to spatial heterogeneity, as samples were not always collected in the exact same location over time due to winds and strong tides.

To determine the effects of sampling date and site on mean sediment concentrations at reference sites, a two-way analysis of variance (ANOVA) was conducted for select chemical parameters, with all Inner and Outer Harbour sites. Factors (date, site) and factor interaction (date x site) were considered significant at an alpha of 0.05. When interactions were significant ($p<0.05$), date and site were split and analyzed separately within factors. The Kolmogorov-Smirnov test of normality and Levene's Median test of equal variance were used prior to all ANOVAs to test data assumptions. Data were transformed using various methods (i.e., log, reciprocal) to meet the assumption of normality and equal variance, where possible. The Holm-Sidak method was used for pairwise multiple comparisons after 2-way ANOVAs (SigmaStat 3.5 or Minitab 16.2.3). Since Site 13 was not sampled in August 2011, this created an unbalanced design for the two-way ANOVA for the Outer Harbour; therefore the analysis was run twice, once excluding all August 2011 and once excluding Site 13 data.

Results and Discussion

BENTHIC COMMUNITIES

A number of groups of organisms dominated the benthic infaunal communities at reference sites in the Saint John Harbour. The most abundant group of organisms at Inner Harbour sites were polychaete worms, which ranged from 74-93% of individuals, on average (Figure 2). Polychaetes at Inner Harbour sites were predominantly *Cossura longocirrata*, a deposit-feeding species which represented 36-77% of individuals at Inner Harbour sites. Infaunal invertebrates at the Outer Harbour sites were dominated by both polychaetes (40-67%) and bivalves (30-54%; Figure 2). *Cossura longocirrata* comprised a much smaller fraction of the total polychaetes at Outer Harbour sites when compared to Inner Harbour sites. Bivalves were more common at Outer Harbour sites than Inner Harbour sites; the most common species was the deposit feeder *Nucula proxima* (21-51% of individuals). Nematodes were abundant in a number of samples from Site 01 in the Inner Harbour, comprising 15% of the infaunal individuals at this site. However, the relative abundance of nematodes at Site 01 varied considerably both between sampling dates (1-37%; see data by date in Appendix B; Table B-4) and among replicates collected on the same date (replicate-specific data not shown). The abundance of nematodes may have been underestimated because most are <0.5 mm and would not have been retained by the sieve. Crustaceans, primarily amphipods and cumaceans (hooded or comma shrimp), comprised 12% of the benthic community at Site 06 in the Outer Harbour, but were less abundant at other sites. Abundance of

these 2 groups may have also been underestimated due to the high mobility of the organisms. Other taxonomic groups (e.g., Bryozoa, Chordata, Cnidaria, Echinodermata, Nemertea, Sipuncula) represented ≤ 2% of the infaunal community at all sites.

Infaunal assemblages in the size range (meiofauna) of those found at the reference sites in Saint John Harbour are characteristically found in the top 5 centimeters of estuarine fine muddy sediments (Kennish 1986). The spatial distribution of benthic invertebrates is affected by a variety of environmental factors (salinity, sediment characteristics, water depth). In addition to those physicochemical factors, predation and competition for space and food among infaunal species may be responsible for the difference in species composition observed between the Inner and Outer Harbour.

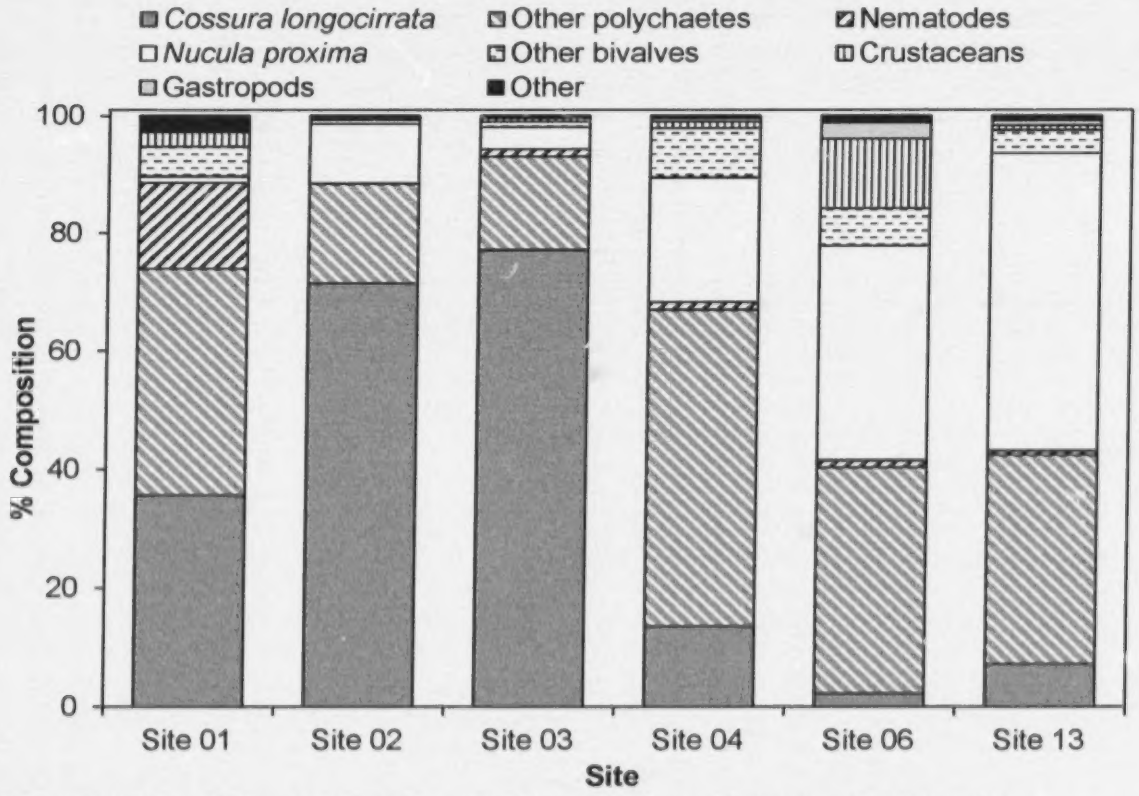

Figure 2. Percentage composition of individuals by major groups of infaunal invertebrates in sediment grab samples from reference sites in the Inner (Sites 01, 02, 03) and Outer (Sites 04, 06, 13) Saint John Harbour. Data are means of n = 5-10 samples on each of 5-6 sampling dates in 2011-2013 (see Appendix B; Table B for data by date).

SEASONAL AND INTERANNUAL VARIATION

Total abundance of benthic invertebrates varied widely across sites and dates, ranging from 5 individuals m^{-2} at Site 01 in June 2012 to 1466 individuals m^{-2} at Site 02 in August 2011 (Figure 3). There was a statistically significant interaction between date and site for total invertebrate abundance at reference sites in Saint John Harbour (Appendix C; Table C-1); therefore, seasonal variation was assessed on a site-specific basis. At Site 02, abundance was significantly higher in August 2011 and October 2011 than April 2012 and June 2012 (Figure 3). At Site 03, abundance in October 2011 was significantly higher than June 2012. For Site 01 in the Inner Harbour and Sites 04, 06, and 13 in the Outer Harbour, there were no significant among-date differences in total invertebrate abundance. In addition, abundance at Sites 02 and 03 were significantly higher than at other sites in both August 2011 and October 2011 (Appendix C; Table C-1).

Mean species richness ranged from 2.6 at Site 01 in June 2012 to 22.9 at Site 06 in August 2011 (Figure 4). There was a significant interaction between date and site for species richness of invertebrates so temporal analyses were done within site (Appendix C; Table C-1). At Site 01, richness was significantly higher in August 2011 and October 2011 than April 2012 and June 2012 (Figure 4). At Site 02, richness was significantly higher in October 2011 than on other dates. At Site 04, richness in August 2011 was significantly higher than June 2012. For Sites 03, 06, and 13, there were no significant among-date differences in species richness. In addition, species richness was lowest at Site 01 across all dates and was significantly lower than some of the other sites (Appendix C; Table C-1).

Mean diversity (H') ranged from 0.24 at Site 02 in August 2011 to 2.4 at Site 06 in October 2011 (Figure 5). There was a significant interaction between date and site for diversity (H') of invertebrates so temporal comparisons were done within site (Appendix C; Table C-2). At Site 02, diversity was significantly higher in April 2012 and June 2012 than in August 2011 (Figure 5). At Site 03, diversity was significantly higher in October 2011 than in August 2011. Diversity at Site 04 was significantly higher in August 2011 than June 2012. At Site 06 diversity was significantly higher in October 2011 and June 2012 than in August 2011. For Sites 01 and 13, there were no significant among-date differences in diversity.

There were some interannual differences in total invertebrate abundance among and between sites. For comparisons of total invertebrate abundance between October 2011 and October 2012, both date and site were significant factors but there was no significant interaction between date and site (Appendix D; Table D-1). Abundance at Sites 02 and 03 was significantly higher than at all other sites and was significantly higher in October 2011 than October 2012 (Appendix D; Figure D-1). For June 2012 and June 2013, there was a significant interaction between date and site so analyses were done within site (Appendix D; Table D-1). At Sites 01 and 04, abundance was significantly higher in June 2013 than June 2012 (Appendix D; Figure D-1). For Sites 02, 03, 06, and 13 there were no significant differences in abundance between dates.

Abundance at Site 01 was significantly lower than at other sites in both June 2012 and June 2013 (Appendix D; Table D-1).

For comparisons of richness between October 2011 and October 2012, date and site were both significant factors, but there was no significant interaction between date and site (Appendix D; Table D-1). Species richness was significantly higher in October 2011 than October 2012, but there was only a 12% difference between mean estimates of richness (Appendix D; Figure D-2). Species richness at Site 01 was significantly lower than at other sites, except Site 13 (Appendix D; Figure D-2). For comparisons of richness between June 2012 and June 2013, only site was a significant factor (Appendix D; Table D-1). Species richness at Site 06 was significantly higher than at other sites, which did not differ significantly from one another (Appendix D; Figure D-2).

For comparisons of diversity (H') between October 2011 and October 2012, only site was a significant factor (Appendix D; Table D-2). Diversity at Sites 04, 06, and 13 in the Outer Harbour was significantly higher than at Inner Harbour sites (01, 02, 03), which did not differ significantly from one another (Appendix D; Figure D-3). Diversity at Site 06 was significantly higher than at Site 13. For comparisons of diversity between June 2012 and June 2013, there was a significant interaction between date and site so analyses were done within site (Appendix D; Table D-2). At Site 01 diversity was significantly higher in June 2013 than in June 2012 (Appendix D; Figure D-3). For all other sites (02, 03, 04, 06, and 13), there were no significant differences in diversity between dates.

In MDS plots examining multivariate similarity in the benthic invertebrate community between samples for the seasonal (Figure 6) and inter-annual comparisons (Figure 7), Sites 02 and 03 in the Inner Harbour grouped together and separately from the Outer Harbour sites, and Site 01 was more variable than the other sites. For the seasonal comparison, there was a significant interaction between site and date (PERMANOVA, Appendix C, Table C-3). For Site 01, within-site similarity of replicate samples on a given date ranged from 25-60% and average similarity between dates ranged from 12-44% (Appendix C; Table C-3). For all other reference sites, average similarity of invertebrate assemblages both within and between dates was higher and ranged from 45-80% (Appendix C; Table C-3). For the interannual comparison, there was again a significant interaction between site and date (PERMANOVA, Appendix D, Table D-3). For Site 01, within-site similarity of replicate samples on a given date ranged from 31-55% and average similarity between dates ranged from 14-42% (Appendix D; Table D-3). For all other reference sites, average similarity of invertebrate assemblages both within and between dates was higher and ranged from 41-72% (Appendix D; Table D-3).

Overall, the results indicated that there was significant spatial and temporal variability in both univariate (total abundance, species richness, and diversity) and multivariate metrics of the infaunal invertebrate community at reference sites in Saint John Harbour. A high degree of spatial (e.g. Ysebaert and Herman, 2002, Boesch et al., 1976), seasonal (e.g. Chainho et al., 2007), and interannual (e.g. Ysebaert and Herman, 2002)

variability of infaunal invertebrate communities is typical of temperate estuaries. Spatial variation in abundance and distribution of infaunal species is often related to variation in sediment characteristics (Snelgrove and Butman, 1994) and physical gradients in the estuary (salinity, depth), as well as biotic interactions among species. Some of the seasonal and annual variation in infauna at reference sites in Saint John Harbour may be attributed to changes in sediment characteristics (see section 3.2). However, temporal variation is likely also related to temporal variation in recruitment patterns of different infaunal species.

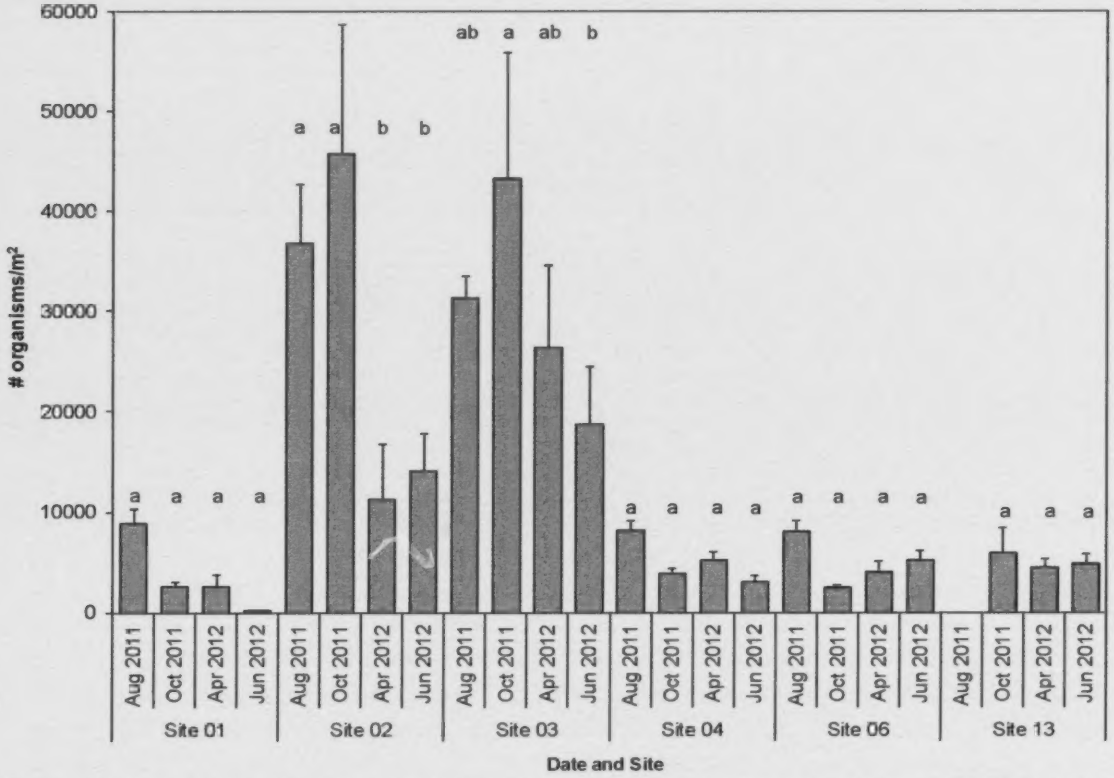

Figure 3. Seasonal variation of total benthic invertebrate abundance in sediments from Saint John Harbour reference sites, 2011-2012. Different letters indicate significantly different means for post-hoc comparisons (Holm-Sidak test, $p < 0.050$) of dates within each site following the detection of a significant date x site interaction. Data are means (± SE) of n = 5-10 samples on each sampling date per site.

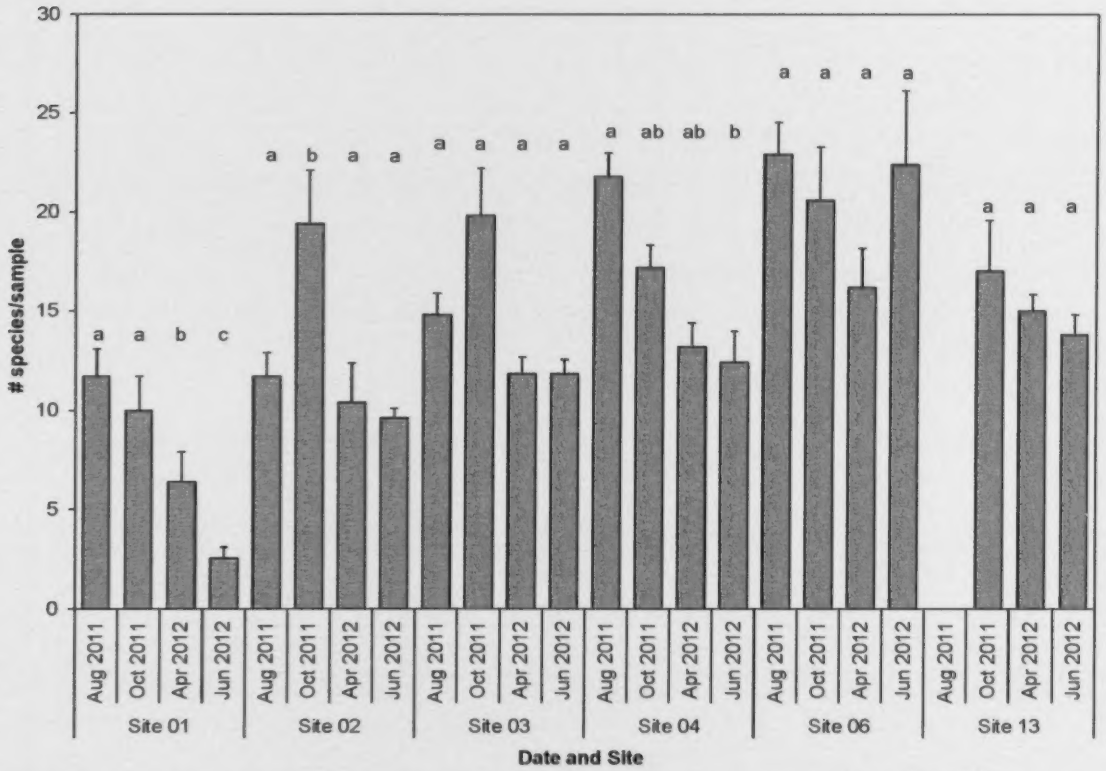

Figure 4. Seasonal variation of infaunal invertebrate species richness in sediments from Saint John Harbour reference sites, 2011-2012. See Figure 3 for description.

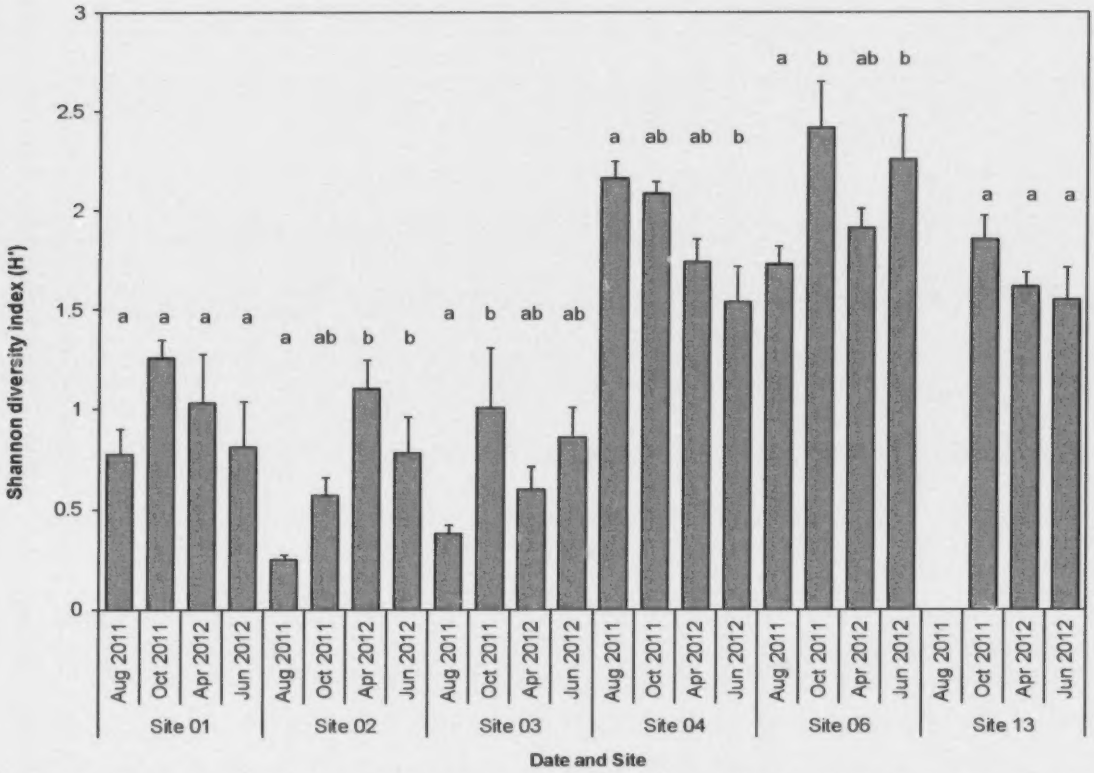

Figure 5. Seasonal variation of Shannon diversity index (H') of benthic invertebrates in sediments from Saint John Harbour reference sites, 2011-2012. See Figure 3 for description.

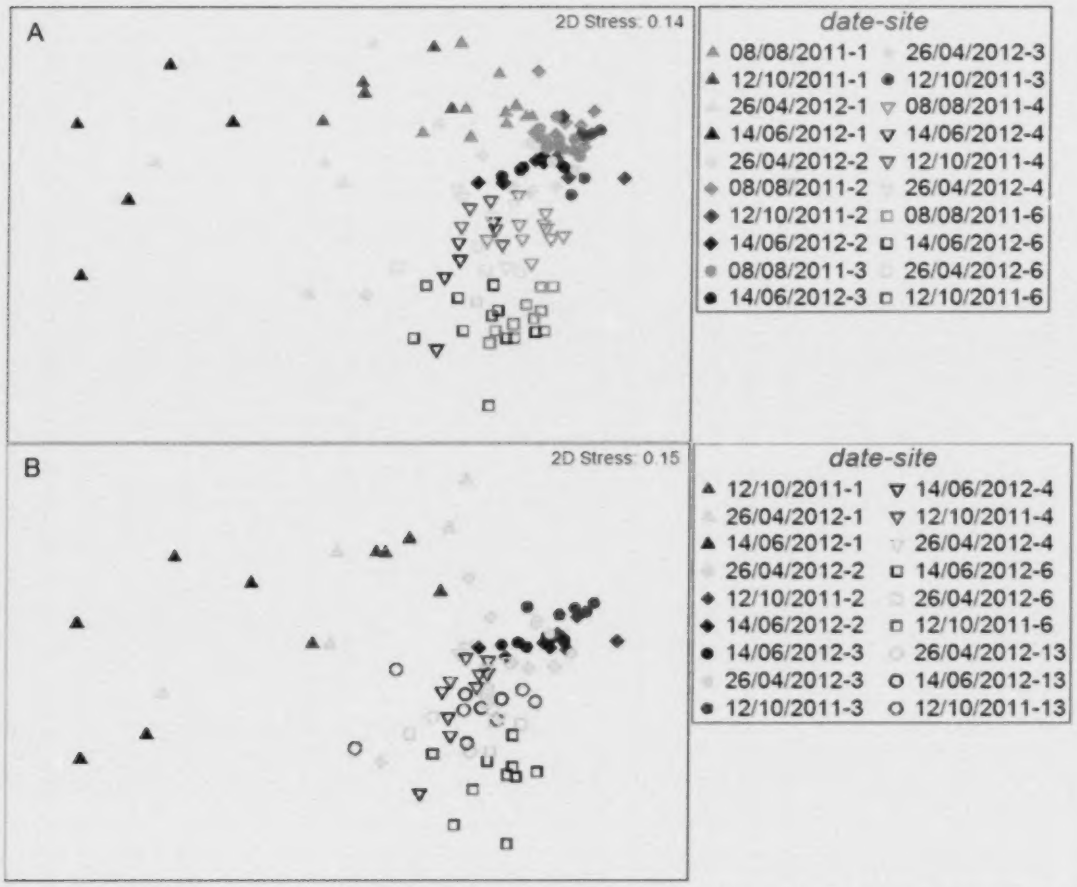

Figure 6. MDS plot of multivariate similarity in invertebrate assemblages among Saint John Harbour reference sites and dates (dd/mm/yyyy) based on Bray-Curtis similarity of square root transformed data for Year 1. Seasonal comparison for Year 1 with A) Site 13 excluded because it was not sampled in August 2011, and B) August 2011 data excluded because Site 13 not sampled at that time. Solid symbols are Inner Harbour sites and open symbols are Outer Harbour sites.

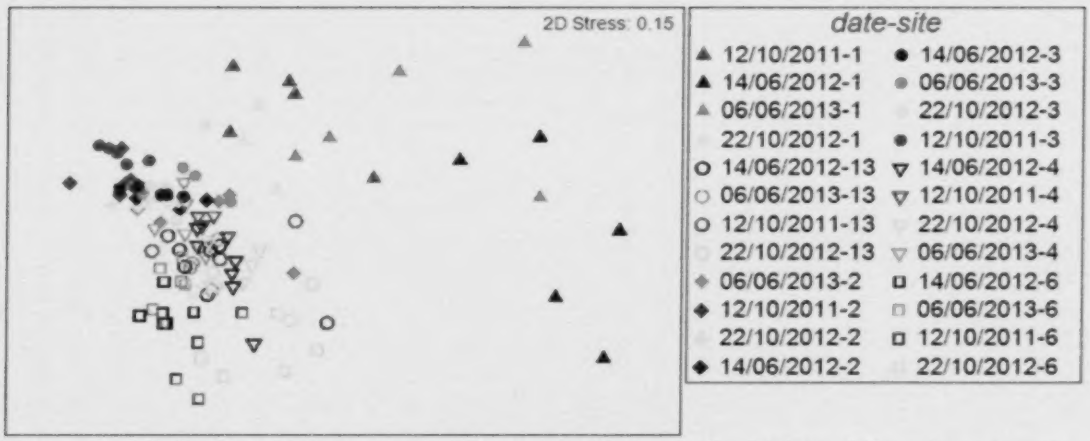

Figure 7. MDS plot of interannual differences (dates indicated as dd/mm/yyyy) and variation among sites for invertebrate assemblages at Saint John Harbour reference sites based on Bray-Curtis similarity of square root transformed data. Solid symbols are Inner Harbour sites and open symbols are Outer Harbour sites.

SEDIMENT PHYSICAL CHARACTERISTICS

Sediments collected from reference sites in the Inner Harbour were predominantly silt-clay (~80% on average) and contained varying proportions of fine-medium sand (~16% on average; Figure 8). Sediments from the Outer Harbour were also predominantly silt-clay (~56-80% on average), but typically contained a greater proportion of fine-medium sand (~20-35% on average) than Inner Harbour sediments. Coarse sand and gravel typically comprised less than 10% of the sediment, on average, with the exception of two sampling events (see data by date in Appendix E; Table E-1). In three of five replicates collected at Site 01 in April 2012, coarse material comprised 25-90% of the samples, and in three of seven replicates collected at Site 06 in October 2011 coarse material comprised ~30% of the samples (replicate-specific data not shown). On previous sampling dates, these stations were characterized by ≤ 10% coarse material, suggesting an uncovering event at each station between sampling events. In all subsequent sampling these two sites were characterized by ≤ 10% coarse material. In general, grain size of sediment samples collected in the present study was similar to that reported in other studies of Saint John Harbour (Parrott et al., 2002; Envirosphere, 2003). A number of sediment samples appeared to be lightly anoxic based on the general description of sediment colour at the time of sampling (see Appendix B; Table B-2). This typically occurred in samples with the greatest penetration depth and was most evident at the bottom of the samples, which is not expected to affect the benthic infaunal community present.

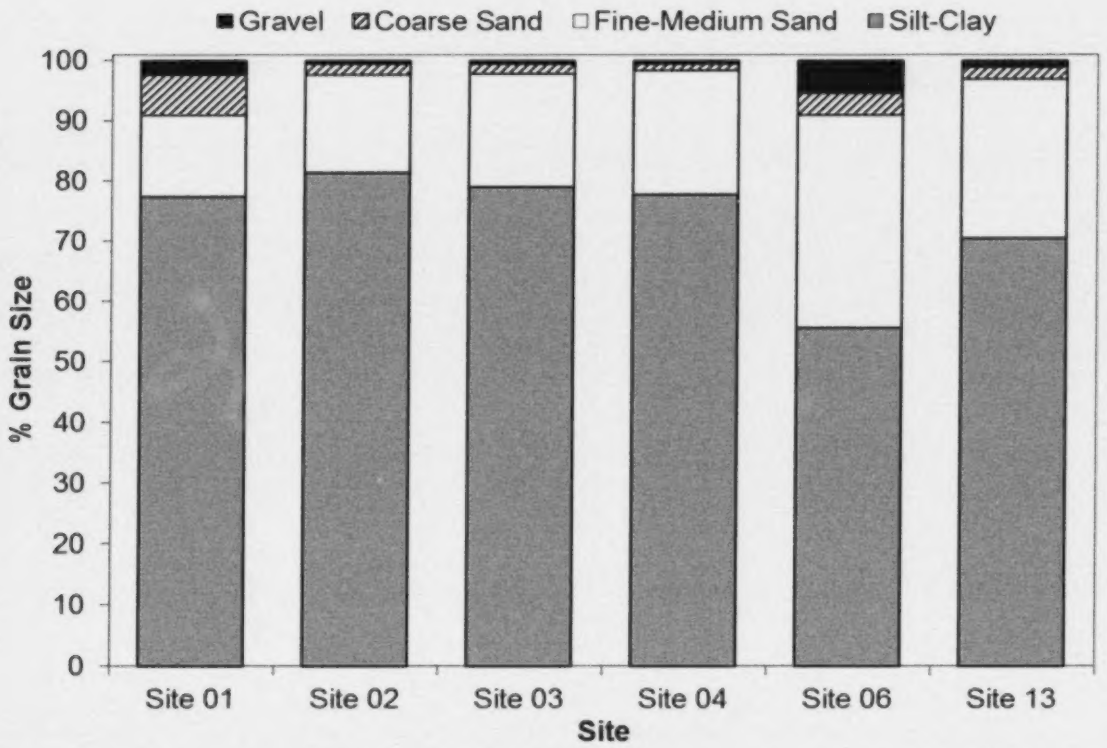

Figure 8. Grain size distribution of sediment at reference sites in the Inner (Sites 01, 02, 03) and Outer (Sites 04, 06, 13) Saint John Harbour. Data are means of n = 5-10 samples on each of 5-6 sampling dates in 2011-2013 (see Appendix E; Table E-1 for data by date).

Total organic carbon was low in sediments collected from Saint John Harbour reference sites, ranging from 0.21 to 1.7%. On average, TOC ranged from 0.66-0.88% at Inner Harbour sites and from 0.54-0.71% at Outer Harbour sites (Figure 9). These data are within the range of sediment TOC values reported in other studies of Saint John Harbour (Parrott et al., 2002; Envirosphere, 2003).

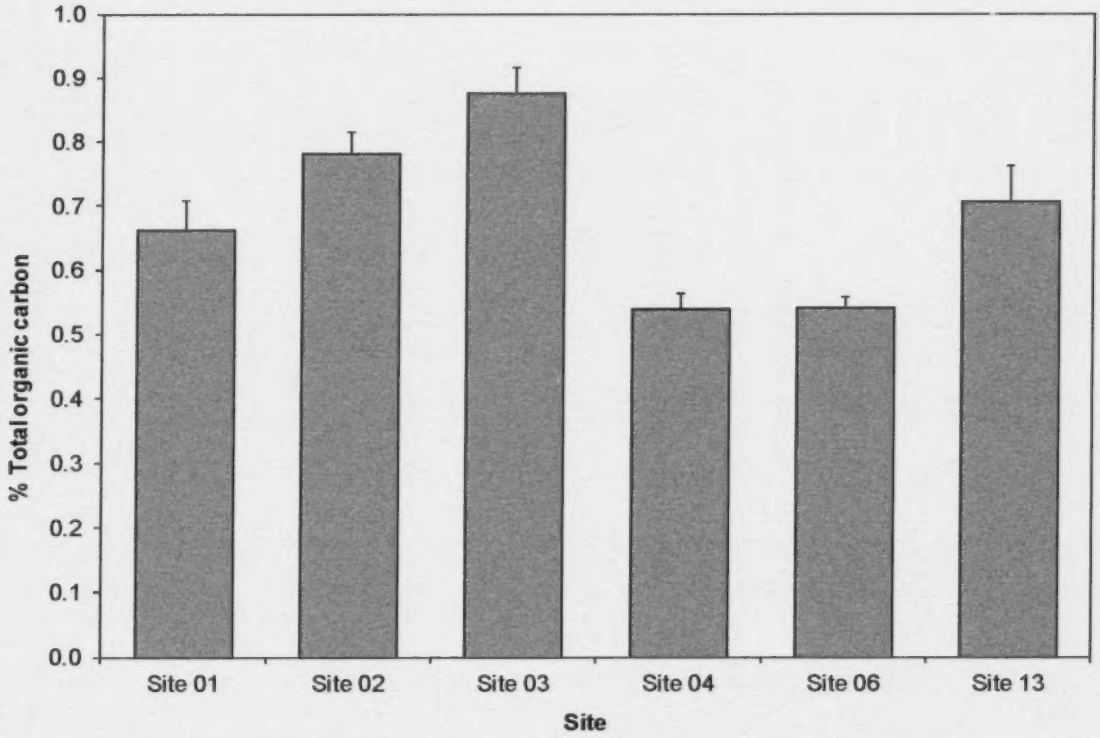

Figure 9. Total organic carbon content of sediment at reference sites in the Inner (Sites 01, 02, 03) and Outer (Sites 04, 06, 13) Saint John Harbour. Data are means (± SE) of n = 5-10 samples on each of 5-6 sampling dates in 2011-2013 (see Appendix E; Table E-1 for data by date).

RELATIONSHIP BETWEEN INFAUNAL INVERTEBRATES AND SEDIMENT CHARACTERISTICS

Linear models were used to determine if sediment parameters (% moisture, % TOC, % LOI_{950}, and *Mz*) explained the variation in mean abundance, richness, and diversity of benthic invertebrates among sites and sampling dates. The best fit model for mean total abundance included only sediment % moisture, to which it was positively related and explained 33% of the variance in abundance ($F_{1,33}$=16.3, p=0.0003, r^2=0.33), while the best model for mean Shannon diversity index (H') was a negative relationship to sediment % moisture, which explained 42% of the variance in diversity ($F_{1,33}$=24.3, $p=2.26x10^{-5}$, r^2=0.42). In contrast, for species richness, the best fit model included only the intercept, indicating no significant relationship to sediment parameters.

To examine the relationship of sediment characteristics to the multivariate measures of the benthic community, the BEST procedure was used to determine the set of abiotic factors whose similarity matrix best correlated to that of the similarity matrix of the biological data. This analysis indicated that for the seasonal comparison, the best fit model of sediment characteristics to the benthic community included % moisture and *Mz* (ρ_s = 0.477) when site 13 was excluded and only *Mz* (ρ_s = 0.357) when August 2011 was excluded (due to unbalanced design). For the interannual comparisons, correlation of the community similarity matrices to those of sediment characteristics demonstrated that the best fit model for October 2011 versus October 2012 included % moisture and *Mz* (ρ_s = 0.331) and that for June 2012 versus June 2013 included % TOC and *Mz* (ρ_s = 0.242).

Correlations between sediment type and infaunal invertebrate distributions have been documented in many studies (reviewed by Snelgrove and Butman, 1994). At the Saint John Harbour reference sites, this study's analyses detected some relationships between the benthic infaunal community and sediment characteristics. However, because the sediment was relatively similar at all of the reference sites (primarily silt/clay with relatively low organic matter content), there was not a large range of values of sediment characteristics over which to examine these relationships, and the infaunal species found at all of the reference sites were characteristic of muddy habitats. Consequently, characteristics of the benthic infauna community at the reference sites in Saint John Harbour were not strongly correlated with sediment parameters.

SEDIMENT CHEMISTRY

Several metals, PAHs, and PCBs were measured in the sediments collected from reference sites in the Saint John Harbour. Of the 22 elements analyzed in sediment, 19 were measured at concentrations above the LOQ in all or most sediment samples (see Table 6). Silver, thallium, and uranium were below the LOQ in the majority of sediment samples and have not been reported. Phenanthrene, fluoranthene, and pyrene were the dominant PAHs in Saint John Harbour sediments, on average each comprising between 15-24% of the total PAHs (data not shown). PCBs 8, 22, 26, and 28 were the dominant congeners, on average each comprising 11-19% of the total PCBs (data not

shown). Sediment concentrations of metals and organics typically varied by less than a factor of 10 between maximum and minimum measured values of all samples (across sites and over time), and in most cases by less than a factor of 5. The exceptions were copper and total PAHs for which concentrations varied by factors of ~85 and ~15-40, respectively, across all samples. In general, sediment concentrations (based on the averages of all data) were similar between the Inner and Outer Harbour reference sites (Table 6).

Concentrations of metals and organics in sediments were compared to Canadian Council of Ministers of the Environment (CCME) – Interim Sediment Quality Guidelines (ISQG), established for the protection of marine life. These numerical guidelines are equivalent to threshold effect levels (TEL), which represent the concentration of a chemical below which adverse biological effects are expected to occur rarely (CCME, 1999). Where ISQG-TELs for select parameters did not exist, sediment concentrations were compared to existing U.S. National Oceanic and Atmospheric Administration (NOAA) – Screening Quick Reference Tables (SQuiRT) TELs (Buchman, 2008). Surveys conducted in 2001 reported that almost all metal concentrations in Saint John Harbour sediments were below the ISQG-TELs for arsenic, cadmium, chromium, copper, lead, and zinc (mercury, PAHs, and PCBs were not measured; Parrott et al., 2002). In the present study, arsenic and nickel were the only chemicals to exceed sediment quality guidelines. Arsenic exceeded the ISQG-TELs of 7.2 mg/kg dw in 39% of Inner Harbour samples and 13% of Outer Harbour samples, by up to a factor of 2. Nickel exceeded the SQuiRT-TEL of 16 mg/kg in 72% of Inner Harbour samples and 50% of Outer Harbour samples, by up to a factor of 2. Arsenic and nickel did not exceed the CCME and SQuiRT probable effect levels (PEL) of 42 and 43 mg/kg dw, respectively; PEL is the sediment concentration above which adverse effects to benthic invertebrates are expected to occur frequently (CCME, 1999). Arsenic is naturally elevated in rock, soil, and sediment of some areas of Atlantic Canada with natural ranges reported from 4-15 mg/kg for the Bay of Fundy and 9-27 mg/kg in Passamaquoddy Bay, NB (Loring, 1982; Loring et al., 1988).

Table 6. Concentrations of metals and organics in sediment collected from reference sites in Saint John Harbour, 2011-2013. Data are based on n = 5-10 samples from each of 6 sampling sites on 6 sampling dates between August 2011 and June 2013 (except only 1 sampling date for PCBs).

Metals and Organics (mg/kg-dw)	CCME ISQG[a]	Limit of Quantification	Inner Harbour					Outer Harbour				
			Mean	SE	n	Min	max	Mean	SE	n	min	max
Al	na	2.7	19000	500	112	8400	30000	18000	500	101	8900	32000
As	7.2	1.6	6.9	0.1	112[d]	3.9	11	6.0	0.2	101[d]	3.9	15
Cd	0.70	0.08	0.08	0.004	112[c]	<0.08	0.21	0.09	0.004	101[c]	<0.08	0.21
Co	na	0.15	9.2	0.2	112	5.6	14	8.7	0.2	101	5.9	16
Cr	52	0.12	27	1	112	13	40	24	1	101	14	43
Cu	19	0.19	7.7	0.2	112[c]	<0.19	16	5.6	0.4	101[c]	<0.19	17
Fe	na	0.64	21000	400	112	13000	34000	21000	500	101	15000	43000
La	na	1.0	21	0.3	112	13	35	20	0.3	101	12	27
Mg	na	4.3	6500	100	112	3500	9500	5900	130	101	3600	12000
Mn	na	0.03	460	7	112	300	680	390	5	101	280	520
Ni	16[b]	0.13	18	0.4	112[d]	9.0	30	16	0.4	101[d]	7.9	31
P	na	0.67	690	9	112	490	1000	540	10	101	330	920
Pb	30	0.77	9.4	0.2	112	4.9	16	8.8	0.2	101	5.0	17
Rb	na	0.86	51	2	112	8.3	110	43	2	101	7.9	110
S	na	1.1	1700	50	112	610	3600	1800	80	101	570	4900
Se	na	1.1	1.3	0.07	112[c]	<1.1	3.2	1.4	0.08	101[c]	<1.1	3.1
Sr	na	0.004	49	1	112	26	72	45	1	101	29	100
V	na	0.15	41	1	112	21	68	39	1	101	23	64
Zn	124	0.04	47	1	112	27	78	43	1	101	27	89
Total Hg (µg/kg-dw)	130	2.8-4.9	12	1	112[c]	4.1	41	7.7	0.3	101[c]	<3.2	25
Total PAHs	1.7[b]	0.04	0.18	0.02	112[c]	<0.04	1.5	0.14	0.01	101[c]	<0.04	0.60
Total PCBs (µg/kg-dw)	22	2.9-3.7	8.2	0.89	22[c]	<2.9-3.7	18	3.8	0.5	22[c]	<2.9-3.7	9.0

na – no marine sediment quality guideline exists, [a] Canadian Council of Ministers of the Environment (CCME), 1999 – Interim Sediment Quality Guidelines (ISQG) threshold effect level (TEL) for the Protection of Aquatic Life – Marine, [b] Buchman, 2008: US National Oceanic and Atmospheric Administration (NOAA) – Screening Quick Reference Tables (SQuiRT) TEL, [c] # samples < DL: Cd – 50 (Inner), 48 (Outer); Cu – 1 (Inner), 15 (Outer); Se – 47 (Inner), 41 (Outer); Total Hg – 2 (Inner), 9 (Outer); Total PAHs – 9 (Inner), 16 (Outer); Total PCBs – 1 (Inner), 9 (Outer) and [d] # samples exceeding ISQG-TEL: As – 44 (Inner), 13 (Outer) and SQuiRT-TEL: Ni – 81 (Inner), 52 (Outer)

SEASONAL AND INTERANNUAL VARIATION

Seasonal differences were found for some metals and PAHs among reference sites in the Saint John Harbour. There was a significant interaction between date and site for arsenic, lead, zinc, and PAHs (Appendix F; Table F-1); therefore, seasonal variation of sediment concentrations was assessed on a site-specific basis. At Site 01, concentrations of arsenic, lead, and zinc in sediment collected in October 2011 were significantly lower than in other seasons (Figure F-1 to Figure F-4). For Site 02, Pb and Zn concentrations in April 2012 were significantly lower than in some other seasons. Significant differences among sites were detected for arsenic and lead in August and October 2011 (Table F-1). Although there was a significant interaction between site and date for PAHs, post-hoc tests did not detect any significant differences between the combinations of sites and dates. Sediment concentrations at any one particular reference site did not appear to be consistently different than at other reference sites and there were no consistent differences in contaminant concentrations between Inner and Outer Harbour reference sites (Appendix F; Table F-1).

In general, over a 10-month period there was no consistent evidence of significant seasonal variation of sediment concentrations of metals and PAHs at reference sites in the Saint John Harbour. Seasonal differences in sediment quality have been investigated in studies of other estuarine environments. In a coastal wetland of Hong Kong, there was significant temporal variation in metal concentrations (Cd, Cu, Ni, Zn) between four seasons; however, this differed across metals and there was no general trend for the contaminants studied (Lau, 2000). In an estuary of eastern England, sediments collected every 2 months over a 22-month period showed significant seasonal differences in metal concentrations. Three select metals (Cd, Hg, Zn) showed similar temporal trends at three sites representing upper, middle, and lower reaches of the estuary, with maximum concentrations measured during the winter (December-February) and minima during the summer (July-September) (Wright and Mason, 1999).

No significant between-year differences were found for sediment contaminant concentrations in Saint John Harbour. For sediments collected in October 2011 and 2012, there was a significant interaction between date and site for arsenic, zinc, and total PAHs (Appendix G; Table G-1); therefore, interannual variation of sediment concentrations was assessed on a site-specific basis. No significant differences were detected between October 2011 and October 2012 at any of the sites (Figure G-4). Arsenic and zinc concentrations were highest at Sites 06 and 02, respectively, in October of 2012 (Figure G-1 to Figure G-4). Contaminant concentrations of sediment samples collected in June 2012 and 2013 showed a significant interaction between site and date only for As, but post-hoc comparisons did not detect any differences between years at any of the sites. For Zn, Pb, and total PAHs, concentrations did not vary significantly by date or site and there was no significant interaction between these two factors (Appendix G; Table G-1). In October 2011, metal and PAHs concentrations at Sites 02 and 03 were consistently higher than those at Sites 01 and 04; however, there were no between-site differences in sediment concentrations in October 2012, June 2012, and June 2013 (Appendix G; Table G-1).

In general, in the two years of this study there was no consistent evidence of significant interannual variation of sediment concentrations of metals and PAHs at reference sites in Saint John Harbour. Monitoring of another historically contaminated harbour in Atlantic Canada, Sydney Harbour, Nova Scotia, over a four year period (2009-2012; baseline and 3 years remediation) showed little temporal variability in sediment concentrations of metals (As, Cd, Cu, Pb, Hg, Zn); however, concentrations of total PAHs, the major contaminant of concern, increased compared to baseline during the onset of local remediation activities (Walker et al., 2013).

SOURCES OF UNCERTAINTY

Potential sources of uncertainty during sampling in the field and processing in the laboratory include:

1) Sampling in repeated locations: wind and strong tidal currents during some of the sampling events led to some drifting in between grab samples and, therefore, to a wider distribution of the samples within certain sites and sampling dates, potentially increasing spatial variability for some sites. The estimated maximum extent of the sampled area at a site was 100-400 m.

2) External factors: sediment movement (deposition, resuspension, and transport) occurs within the Harbour and changes in sediment distribution during storm events could contribute to temporal variation in sediment chemistry and the benthic community, particularly at certain sites (e.g., changes in sediment grain size at Site 01 between sampling dates).

3) Sediment chemistry analyses: certified reference materials, method blanks, surrogates, method spikes, and duplicate samples were included as part of a QA/QC program to quantify measurement variability and error and address uncertainty. Relative percent difference (RPD) was used to determine the precision of the duplicate samples.

4) Variation in condition of preserved organisms: the delicate nature of marine invertebrates makes them susceptible to damage during sieving and processing. Despite being preserved rapidly while still in the field, condition of organisms upon identification varied temporally, most likely due to seasonal variation in body condition and size.

To address the question of the taxonomic resolution necessary to detect spatial and temporal variability in the benthic invertebrate community, a taxonomic sufficiency assessment, using second-stage MDS, was done in which abundances were aggregated to the levels of genus, family, suborder, order, infraclass and class (note that many polychaetes worms are not classified by orders but by infraclasses) and the correlation between similarity matrices for the data at different taxonomic resolutions was determined (Appendix H, Table H-1). The analyses suggest that multivariate patterns of temporal (seasonal and interannual) and spatial variability can still be

detected at higher taxonomic resolution. For example, Spearman's rank correlations, ρ_s, were ≥0.98 at the family level compared to species level. Transformation also had effects on the patterns detected at the different levels of taxonomic resolution (Appendix H, Table H-1).

Due to spatial and temporal variability in the data, power analyses were conducted to determine if the number of samples collected was adequate to detect a range of expected effect sizes for sediment contaminants. Power analyses conducted based on site-specific mean concentrations of arsenic demonstrated that with 5 to 6 samples there was ≥ 80% power to detect a critical effect size equivalent to 2-times the SD (Vanderbilt University PS: Power and Sample Size Calculation v 3.0, 2009; t-test α = 0.05, Table 7). Analyses conducted with the other select metals (Pb, Zn) and total PAHs gave very similar results.

For benthic invertebrates, power analyses (Vanderbilt University PS: Power and Sample Size Calculation v 3.0, 2009; t-test α = 0.10, power = 90%) were done to determine the number of samples necessary to detect changes in total abundance, species richness, and diversity (H'). α = 0.10 and power = 90% were used for the invertebrate power analyses following the approach used in the Environmental Effects Monitoring (EEM) program for the pulp and paper industry (Environment Canada, 2010). These calculations indicated that for total abundance, species richness, and diversity, a minimum of 5 replicate samples were required to detect an effect size of 2 SD, and 18 replicate samples were required to detect an effect size of 1 SD. Because the variability (SD) differed between the population metrics (abundance, richness, and diversity) as well as across sites and dates, when the effect size was expressed in terms of % of the mean, the number of samples needed to detect differences of 75 and 100% of the mean varied among sites and dates (Oct 2011 and 2012 and June 2011 and 2012, Table 8). In general, there was higher power to detect differences in species richness and diversity than total abundance due to the greater variability in abundance. To determine if abundance of individual species was less variable than total abundance and would require fewer samples to detect changes over time, 5 species were selected based on having a dispersion value <3 (D=1.46-2.35) and total abundance across all samples >150 individuals (abundance 152-1500). The species selected were two species of polychaetes, *Ninoe nigripes* and *Nephtys incisa,* two bivalves *Arctica islandica* and *Nucula delphinodonta,* and a gastropod *Ilyanassa trivittata* (Figure D-4). Power analyses for these species with low intra-site variability indicated that an extremely large number of samples would be needed to detect changes in abundance of *A. islandica, N. delphinodonta*, and *I. trivittata* equal to 100% of the mean (Table 8). The number of samples needed to detect effects of this size for *N. nigripes* was quite variable among sites and dates, while effects of this magnitude would more easily be detected for the polychaete *N. incisa* (Table 8). However, detection of changes of 100% of the mean generally required lower sample size for total abundance than for any of the individual species.

Table 7. Power (%) based on site-specific mean concentrations of arsenic in sediments collected from reference sites in Saint John Harbour, 2011-2013. Standard deviation (SD) based on grand mean of n = 5-6 sampling dates for each site.

Site	n	SD (σ)	Power (%) at critical effect size[a]		
			1x SD	2x SD	3x SD
01	6	1.27	32	88	99
02	6	0.73	32	88	99
03	6	0.52	32	88	99
04	6	0.54	32	88	99
06	6	1.17	32	88	99
13	5	1.23	25	79	98

[a] Vanderbilt University PS: Power and Sample Size Calculation v 3.0: t-test, $\alpha = 0.050$, σ = SD, critical effect size δ = 1-, 2-, or 3x SD

Table 8. Sample size needed to detect a difference of 75% and 100% of mean of total abundance, abundance of 5 individual species, species richness, and diversity (H') of benthic invertebrates at reference sites in Saint John Harbour, with power of 0.90 and α = 0.10, in October 2011 and 2012, and June 2012 and 2013.

	Site	Number of replicates (n) at critical effect size (δ)[a]							
		October				June			
		2011		2012		2012		2013	
		75%	100%	75%	100%	75%	100%	75%	100%
Total abundance	01	7	5	19	11	28	16	13	8
	02	13	8	9	5	12	7	32	18
	03	14	8	7	4	15	9	23	13
	04	3	2	3	2	7	4	6	4
	06	3	2	8	5	7	4	3	2
	13	29	16	16	9	6	4	4	3
Abundance *Ninoe nigripes*	01	-	-	155	88	-	-	68	39
	02	18	11	4	3	6	4	48	27
	03	28	16	9	5	8	5	24	14
	04	12	7	16	10	36	21	4	3
	06	4	3	15	9	5	3	9	5
	13	12	7	13	8	8	5	6	4
Abundance *Nephtys incisa*	01	29	17	11	7	68	39	152	86
	02	5	3	2	2	3	2	32	18
	03	4	2	5	3	12	7	24	14
	04	5	3	9	6	10	6	20	12
	06	12	7	9	5	4	3	6	4
	13	10	6	19	11	6	4	12	7
Abundance *Arctica islandica*	01	-	-	155	88	-	-	-	-
	02	26	15	68	39	-	-	155	88
	03	31	18	26	15	-	-	58	33
	04	9	5	10	6	28	16	10	6
	06	-	-	-	-	-	-	-	-
	13	115	65	58	33	155	88	26	15
Abundance *Nucula delphinodonta*	01	-	-	155	88	-	-	-	-
	02	68	39	58	33	58	33	34	20
	03	-	-	13	8	34	20	107	60
	04	55	31	22	12	24	14	10	6
	06	155	88	155	88	152	86	81	46
	13	66	37	155	88	68	39	21	12
Abundance *Ilyanassa trivittata*	01	-	-	58	33	-	-	-	-
	02	155	88	18	10	58	33	155	88
	03	26	15	62	35	68	39	68	39
	04	155	88	-	-	58	33	26	15
	06	13	8	36	20	7	5	21	12
	13	68	39	34	20	58	33	68	39
Richness	01	5	4	3	2	7	4	7	4
	02	4	3	2	2	2	2	2	2
	03	3	2	2	2	2	2	2	-
	04	2	2	2	2	3	3	2	2
	06	4	3	2	2	5	3	3	2
	13	4	3	4	3	2	2	4	3
Diversity	01	2	2	4	3	13	8	3	2
	02	4	3	3	2	8	5	5	3
	03	14	8	5	3	6	4	6	4
	04	-	-	2	2	3	2	-	-
	06	3	2	2	2	3	2	2	-
	13	2	2	2	2	3	2	2	2

DEFINITION OF REFERENCE CONDITIONS

Reference conditions at the sites were defined using the approach of Arcizewski (2014) in which normal ranges of natural variability are derived using thresholds (grand means ± 2SD). Once the expected range of natural variability is established, observation of a measurement outside of that "natural range" would trigger confirmation and further monitoring (see Table 9). In the early stages of monitoring, 2SD of the individuals in the first sample set are used to set a conservative normal range. Once the data from 3 or more sampling periods are available, the normal range can be calculated from 2SD of the means of samples; it is important to note that this estimate of the normal range will not stabilize until at least 8-12 sampling events (Arcisewski, 2014), and the initial conservative range can be used as an outer boundary for determining the level of concern.

Table 9. Tiers and decision triggers for regional environmental monitoring (Wrona and di Cenzo, 2011).

Level	**Trigger**	**Consequence**
Effect	Significant statistical change	Seek confirmation
Warning Sign	Exceeds critical effect size, and is confirmed	Increase monitoring frequency to define extent and magnitude of change
Response Sign	Exceeds critical threshold effect size and is getting worse	Investigate cause
Action Level	Passes probable effects level or water quality criterion	Change in management strategy warranted

Reference levels can be defined at multiple spatial scales (within-site, local reference sites, regional scale), and the data should be evaluated at multiple scales (Greig and Pickard 2014).

- Has the site changed?
- Has the site changed relative to local reference sites?
- Has the site changed relative to regional sites?

To define reference conditions for chemicals in sediment, average concentrations at a site on each sampling date (based on 5-10 replicate samples) were used to determine grand means and SDs on a site-specific basis, an area basis (i.e., Inner and Outer Harbour sites), and a regional basis (i.e., whole harbour). The range of reference conditions was defined as 2-times the SD of the grand mean for the site, area, or region (Appendix I; Table I-1). Values in this table can then be used to assess changes in mean values over time and can be applied to other harbour sites for which baseline data do not yet exist. An example with arsenic graphically shows how the mean concentrations at each site on each sampling date fall within the 2-times SD-range for the site, area, and region (Figure 10; see Table I-1 for specific values).

For benthic invertebrates, we determined the range of reference conditions (2-times the SD of the grand mean) for species richness (Figure 11), total abundance, and diversity for October for each site individually (based on 5 replicate samples), as well as for the Inner and Outer Harbour and the whole Harbour (Appendix J, Table J-1). It should be noted that this definition of reference conditions is based on only two years of sampling, and that 5 to 7 years of data will be required to truly define the range of reference conditions at these sites. The range of reference conditions varied due to the spatial and temporal variability in the invertebrate community. For species richness, the range of reference conditions was larger in the Outer Harbour (Sites 04-06) than in the Inner Harbour (Sites 01-03) (Figure 11). In contrast, for total abundance (Table J-1), the range of reference conditions was much greater in the Inner than the Outer Harbour due to the high variability in total abundance at Sites 02 and 03.

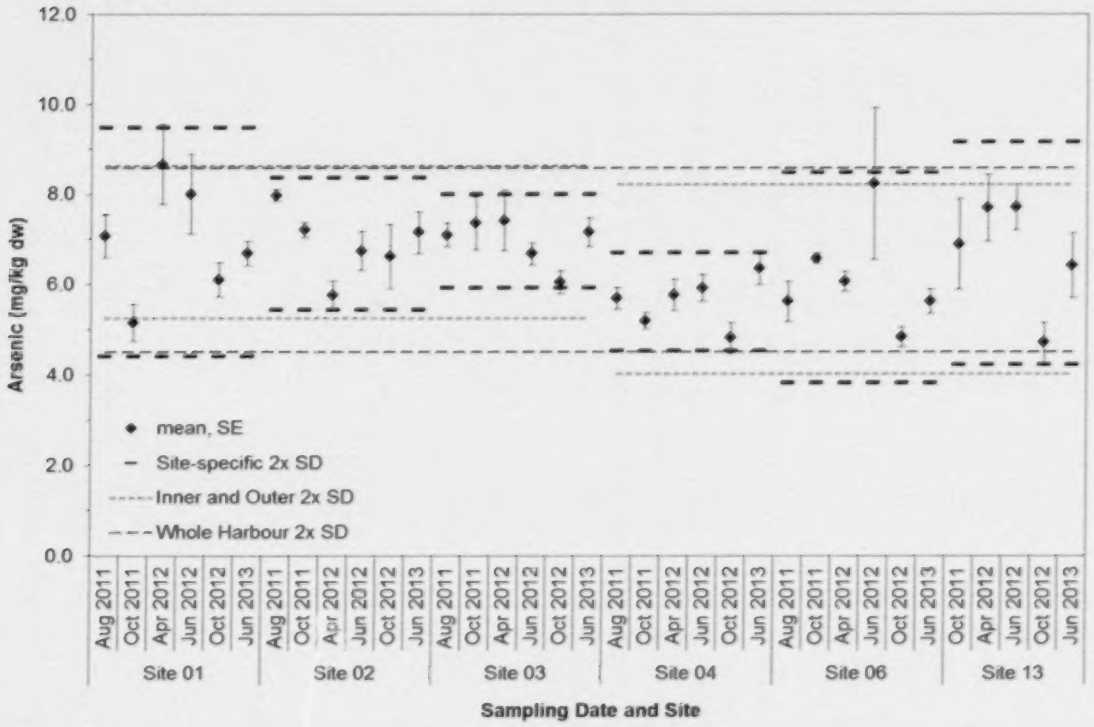

Figure 10. Range of reference site concentrations for arsenic (± 2x SD of grand mean; mg/kg dw) on the basis of site, area (Inner Sites 01, 02, 03 versus Outer Sites 04, 06, 13), and region (whole harbour) in sediment collected from reference sites in Saint John Harbour, 2011-2013.

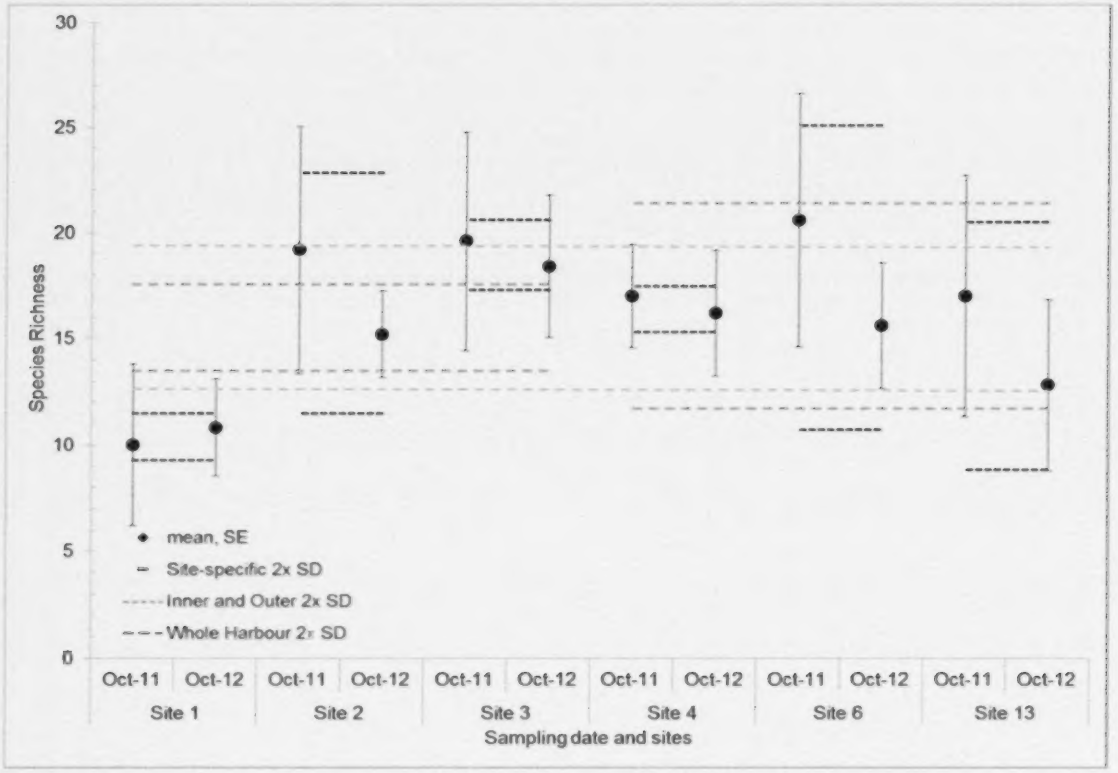

Figure 11. Range of site-specific reference conditions for species richness (± 2x SD of grand mean) of benthic invertebrate samples collected from reference sites in Saint John Harbour in October 2011 and 2012.

RECOMMENDATIONS AND ADVICE FOR LONG TERM MONITORING AND SAMPLING IN SAINT JOHN HARBOUR

Standardization of the sampling design is essential for being able to compare results from studies conducted by different groups. The following are recommendations for infaunal and sediment contaminant sampling in the Saint John Harbour.

Field Methods

1. Reference sites: Ongoing sampling of these six reference sites will allow for the detection of long-term, cumulative changes in the Harbour. These sites should be sampled as part of other monitoring programs to continue to provide baseline data on the overall status of the Harbour.

2. Sampling method: Sampling should be done using a grab, such as the Smith-McIntyre grab used in this study (sampled surface area of the grab of 0.089 m^2), of sufficient size and weight to penetrate the sediment despite strong tidal currents. Concurrent sampling of invertebrates, sediment characteristics, and

contaminants is recommended as it allows for an examination of the relationships between these variables at a small spatial scale (within-site), and the development of predictive relationships that can be applied to other sites.

3. Timing of sampling: Inner Harbour sites should be sampled during or just after high tide (minimum tidal currents approx. 2 hours after high tide) while the deeper Outer Harbour sites should be sampled during low tide.

4. Season of sampling: Community composition of benthic invertebrates changes seasonally and invertebrates tend to be more abundant and easily identified at certain times of the year (e.g. Reynoldson et al, 2003). Sediment sampling at reference sites in Saint John Harbour should be standardized to a single season of the year due to seasonal variability in the benthic invertebrate community. October is preferred due to higher species richness and total abundance at many of the sites, but June is also potentially a good time of year for sampling due to lower variability in abundance and richness at some sites (Figures 3 and 4). August is not recommended for sampling due to the small size of newly recruited individuals of many species at this time of year.

5. Replication: Based on power analyses (see section 3.4), a minimum of 5 samples per site is recommended for both sediment contaminants and benthic invertebrates.

6. Methods for sediment contaminants: The top 5 cm of sediment should be collected using a pre-cleaned corer, put in pre-cleaned glass jars, and frozen until processed. This allows for direct comparisons to the CCME ISQGs.

7. Methods for benthic invertebrates: A minimum penetration depth of 5 cm into the sediment is required. A sampled surface area of at least 0.03 m^2 (area sampled in this study) is needed to ensure adequate numbers of invertebrates are collected. The sample should be sieved on 500 µm mesh to retain the majority of large juveniles and adults of infaunal organisms without retaining too much sediment. A larger mesh size is not recommended due to the very small size of most of the individuals collected. Invertebrates should be preserved in 80% ethanol or buffered formalin.

Laboratory methods:

1. Sediment analysis for metals and PAHs: Sediments should be freeze-dried and macroinvertebrates and larger debris removed. Extraction, clean up and analyses should be done using standard US EPA methods and quality assurance procedures.

2. Sediment characteristics: Organic carbon content and grain size of the sediment should be measured using standard techniques.

3. Infaunal identification: Organisms should be identified to species level where possible. Taxonomic sufficiency analysis indicates that identification to family level would still retain most of the information about patterns across reference sites and dates (Appendix H, Table H-1). However, species-level identification will provide more detailed information for detection of impacts (e.g., pollution indicator species). For example, organically enriched sites in estuaries generally support only a few opportunistic or tolerant species (Rosenberg, 1978). Polychaetes in particular tend to be less diverse and abundant in contaminated estuaries heavily modified by anthropogenic activities involving contaminants (e.g., Johnston and Roberts, 2009). Identification at the species level (when possible) can also be important to monitor invasive or rare species.

Data interpretation:

1. Thresholds for assessing changes in sediment contaminants have been set at 2SDs calculated from site means, means of either the Inner or Outer Harbour data, or Harbour-wide means. These thresholds can be used to determine whether contaminant means of new samples fall within or outside these thresholds. If the latter, confirmation of the results is recommended using additional sampling.

2. Thresholds for assessing changes in infaunal invertebrates have been set at 2SDs calculated from site means because of the variability in invertebrate data among sites. As above, these thresholds can be used to assess changes of concern in the Harbour.

3. When data on reference sites for other harbours are missing, the 2SD values from reference sites in this study could be adopted as threshold criteria until such as time as sufficient data become available to design site specific criteria.

In conclusion, this report provides several seasons and years of baseline data for infaunal invertebrates and contaminants in sediments collected from reference sites in the Saint John Harbour. Results from these analyses were used to develop recommendations for a long-term monitoring program in the Harbour that would allow for assessment of cumulative effects of any new developments. In addition, this report provides some general approaches that could be applied to long-term monitoring programs in other harbours.

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APPENDIX A. Field sampling protocol supplemental information

Figures depicting specific aspects of sediment grab samples are shown below.

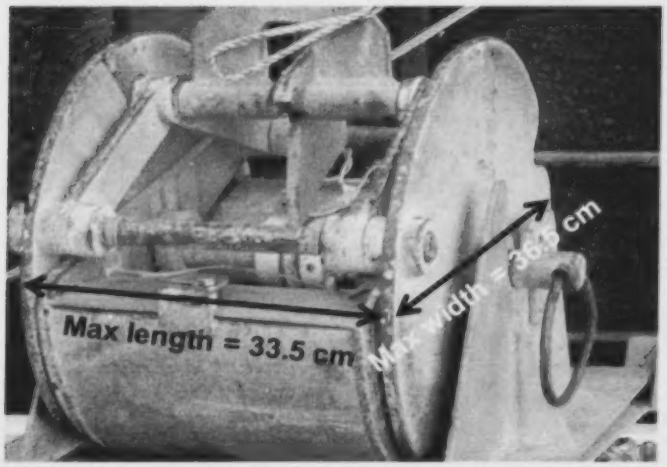


Figure A-1. Smith McIntyre grab sampler. Photo courtesy of L. LeBlanc, 2011.

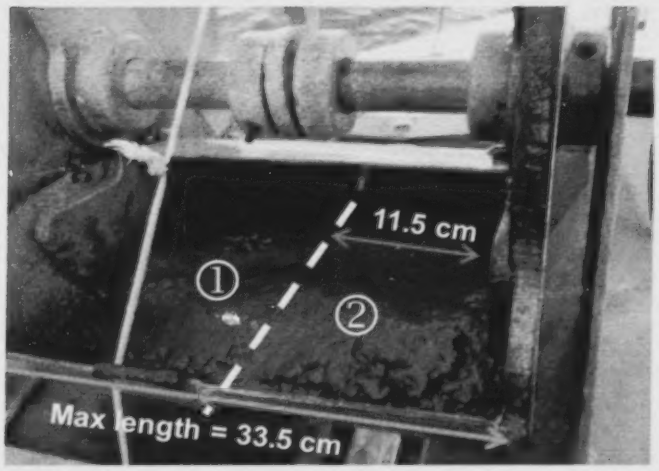


Figure A-2. Example of grab sample of sediment in a Smith McIntyre grab sampler and division of sample along grab midline into 1) physicochemical portion and 2) infaunal portion. Cut-off length for infaunal portion was 11.5 cm, not quite in the middle of the grab which would have been 16.75 cm.

APPENDIX B. Benthic community data

Table B-1. General sediment descriptions noted during sample collection, including anoxia, of surface grab samples from six Saint John Harbour reference sites in 2011-2013.

Date	Site	Sediment general description	Anoxic samples (replicate #, sediment depth shown for samples processed for benthos)
Aug 2011	01	mud, some cores are sandy	
	02	fine mud, organic debris	
	03	fine mud, organic debris	
	04	fine mud, organic debris (shell hash, wood, plant)	
	06	mud, some rocks, shell hash, organic debris	
Oct 2011	01	mostly sand but also some rocks, mud (some replicates), organic debris (plant, mud tubes)	3
	02	fine mud and organic debris (plants, wood)	
	03	fine mud, organic debris (wood, tube of polychaetes)	
	04	mud and sand, shell hash, organic debris	6 (7 cm), 7
	06	mud, pebbles, coarse sand, shells, and organic debris (hydroids, wood)	
	13	mud, rocks, shells, organic debris (wood)	6 (12 cm)
Apr 2012	01	sandy, some mud, some rocks, shells	5 (4 cm); lightly anoxic
	02	clay, mud, some organic debris	
	03	clay, mud and organic debris (plant, wood)	
	04	clay, mud and some sand, lots of organic debris	2, 3 (11 cm), 6 (5 cm), 7; all lightly anoxic
	06	mud, some rocks, shell hash, organic debris	
	13	mud and some rocks, shells, lots of debris (replicate #5)	
Jun 2012	01	mostly sand, some mud and organic debris	
	02	mud, organic debris	1, 3 (11 cm), 4 (10 cm), 5 (11 cm), 6, 7, 8 (10 cm), 9 (12 cm), 10; all lightly anoxic
	03	mud and organic debris	1 (11 cm), 3 (9 cm), 4, 5 (10 cm), 6, 7 (11 cm), 8, 9 (10 cm), 10; all lightly anoxic
	04	clay, mud and some sand, lots of organic debris	1 (8 cm), 2, 3, 4 (8 cm), 6, 7 (11 cm), 8, 9, 10 (9 cm); all anoxic at bottom only

Table B-1. continued

Date	Site	Sediment general description	Anoxic samples (replicate #, sediment depth shown for samples processed for benthos)
	06	mud, some rocks, shell hash, organic debris (wood)	
	13	mud, some rocks, lots of organic debris	1 (12 cm), 8 (11 cm), 9 (8 cm), 10 (8 cm); all light anoxic at bottom
Date	Site	Sediment general description	Anoxic samples (replicate #, sediment depth shown for samples processed for benthos)
Oct 2012	01	sand and mud, some pebbles, some organic debris	
	02	fine mud, lots of organic debris	
	03	clay, mud and organic debris (polychaete tubes)	
	04	fine mud, shell hash, organic debris (wood, plant)	
	06	mud and pebbles, shells	6 (7 cm)
	13	mud, some sand, pebbles, shell hash, organic debris (wood)	
Jun 2013	01	mud, some sand, organic debris	6 (11 cm)
	02	fine mud, organic debris	
	03	mud, organic debris	
	04	fine mud, some shells, organic debris	
	06	mud, sand, pebbles, shells, some organic debris	
	13	mud, pebbles, shell hash, organic debris	

Table B-2. Number of benthic infaunal invertebrate samples collected, processed, and used for data analysis from sediment collected as surface grab samples from six Saint John Harbour references sites in 2011-2013.

Date	Inner Harbour				Outer Harbour			
	Site	collected	processed	data analysis	Site	collected	Processed	data analysis
Aug 2011	01	10	10	10	04	10	10	10
Oct 2011		5	5	5[a]		6	6	5
Apr 2012		5	5	5[b]		10	8	5
Jun 2012		10	5	5		10	5	5
Oct 2012		8	5	5		8	5	5
Jun 2013		8	5	5		8	5	5

Table B-2. continued

Date	Inner Harbour				Outer Harbour			
	Site	collected	processed	data analysis	Site	collected	processed	data analysis
Aug 2011	02	10	10	10	06	10	10	10
Oct 2011		6	5	5		6	6	5
Apr 2012		10	9	5		8	5	5
Jun 2012		10	5	5		10	5	5
Oct 2012		8	5	5		8	5	5
Jun 2013		8	5	5		8	5	5
Aug 2011	03	10	10	10	13	ns	-	-
Oct 2011		6	5	5		6	6	5
Apr 2012		10	6	5[a]		10	6	5
Jun 2012		10	5	5		10	5	5
Oct 2012		8	5	5		8	5	5
Jun 2013		8	5	5		8	5	5

ns - Site 13 not sampled August 2011

[a] 1 sample with <5 cm sediment depth used for data analysis to have a minimum of 5 replicates

[b] 2 samples with <5 cm depth used for data analysis

Table B-3. List of infaunal species identified in sediment collected as surface grab samples from six Saint John Harbour references sites in 2011-2013.

Phylum - Order
Annelida - Polychaeta
Alitta virens (formerly *Nereis virens*)
Ampharete spp.
Aphroditella hastata
Aricidea catherinae
Asabellides oculata
Bipalponephtys neotena
Brada villosa
Capitella capitata
Chaetozone setosa
Chone infundibuliformis
Cossura longocirrata
Dipolydora quadrilobata
Drilonereis longa
Drilonereis magna
Eteone longa
Flabelligera affinis
Glycera dibranchiata
Goniada maculata
Harmothoe spp. (H. extenuata/imbricata)
Hartmania moorei
Laonice cirrata
Levinsenia gracilis
Lumbrineris fragilis
Macrochaeta sp.
Maldanidae (78% *Clymenella torquata*)
Microphthalmus spp.
Nephtys picta
Nephtys caeca?
Nephtys ciliata
Nephtys incisa
Nereis pelagica
Ninoe nigripes
Ophelina acuminata
Owenia fusiformis
Pherusa spp.
Pholoe minuta
Phyllodoce mucosa
Polycirrus spp.
Polydora websteri
Prionospio steenstrupi
Sabellaria vulgaris
Scalibregma inflatum
Scoletoma tenuis
Scoletoma tetraura
Scoloplos acutus
Spiophanes bombyx
Sternaspis scutata
Sthenelais limicola
Syllidae
Terebellides stroemii
Tharyx spp.
Travisia carnea
unknown polychaete - brown and green
Annelida – Oligochaeta
unknown oligochaete
Arthropoda – Amphipoda
Ampelisca macrocephala
Ampelisca vadorum
Aoridae
Argissa hamatipes
Caprella septentrionalis
Casco bigelowi
Deflexilodes intermedius
Dyopedos monacantha
Gammarus sp.
Haploops fundiensis
Harpinia propinqua
Ischyrocerus anguipes
Leptocheirus pinguis
Melita dentata
Photis pollex
Phoxocephalus holbolli
Unciola irrorata
Unciola serrata

Table B-3. continued.

Phylum - Order
Arthropoda - Copepoda
unknown Copepoda
Harpacticoida
Arthropoda - Cumacea
Diastylis spp. (D. polita and D. scuulpta)
Diastylis quadrispinosa
Eudorella spp.
Lamprops quadriplicata
Leptostylis sp.? (juvenile)
Oxyurostylis smithi
Pseudoleptocuma sp.
Arthropoda - Isopoda
Chiridotea coeca
Chiridotea tuftsi
Edotia triloba
Idotea phosphorea
Arthropoda - Nebaliacea
Nebalia bipes
Arthropoda - Ostracoda
unknown Ostracoda
Arthropoda - Sessilia
Balanus balanus
Arthropoda - Trombidiformes
Halacaridae
Bryozoa
Caberea ellisii
Crisia eburnea
Flustra foliacea
Cephalorhyncha
Pycnophyes sp.
Chordata
Dendrodoa carnea
Didemnum albidum
Molgula siphonalis?
Molgula sp. 1
Molgula sp.2
unknown right angle siphon tunicate
Cnidaria
unknown Actiniaria sp.1 - brown
unknown Actiniaria - short white
Clytia sp.
unknown Cnidaria - soft colony
Edwardsia sp. 1
Edwardsiidae (different than sp.1)
Echinodermata
Amphipholis squamata
Ekmania barthii
Mesothuria (Allantis) intestinalis?
Mollusca – Bivalvia
Anomia simplex
Arctica islandica
Astarte undata
Cyclocardia borealis
Ensis directus
Hiatella arctica
Lyonsia hyalina
Macoma balthica
Modiolus modiolus
Musculus sp.
Mysella planulata
Mytilus edulis/trossulus
Nucula delphinodonta
Nucula proxima
Nucula tenius
Nuculana tenuisulcata
Pandora gouldiana
Parvicardium pinnulatum
Periploma aleuticum
Solamen glandula
Spisula solidissima
Thraciidae
Thyasira flexuosa
Thyasira trisinuata?
Yoldia limatula
Yoldia myalis
Yoldia sapotilla

Table B-3. continued.

Phylum - Order	
Mollusca - Gastropoda	Nematoda
Crepidula fornicata	unknown Nematoda
Cylichna gouldii	Nemertea
Diaphana minuta	*Cerebratulus lacteus*
Ilyanassa trivittata	unknown Nemertea
Littorina saxatilis	Oligochaeta
Lunatia heros	unknown Oligochaeta
Nucella lapillus	Phoronida
Propebela concinnula?	*Phoronis muelleri?*
Retusa obtusa	Platyhelminthes
Mollusca - Nudibranchia	unknown Trematoda – yellow
Cuthona sp.	Porifera
Mollusca - Scaphopoda	*Haliclona oculata*
Antalis entalis	Sipuncula
Mollusca - Solenogaster	*Golfingia sp.*
Chaetoderma nitidulum	*Phascolion (Phascolion) strombus strombus*
	unknown Sipuncula sp. 1

Table B-4. Benthic infaunal invertebrate community composition (by % of individuals) from sediment grab samples from six Saint John Harbour references sites in 2011-2013.

	Inner Harbour – Site 01											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		5		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Composition – Major groups (%)												
Polychaetes	92	4	95	2	65	18	52	17	93	3	47	12
Cossura longocirrata	78	5	36	15	20	17	4	4	63	9	14	6
Other polychaetes	14	3	59	14	46	19	48	18	30	6	34	6
Nematodes	6	4	0.9	0.7	31	17	10	6	2	1	37	8
Bivalves	1	0.3	0.2	0.2	0.2	0.2	28	12	2	1	5	5
Nucula proxima	0.6	0.2	0.2	0.2	0	0	0	0	0.8	0.5	5	5
Other bivalves	0.6	0.2	0	0	0.2	0.2	28	12	2	1	0	0
Crustaceans	0.7	0.2	3	2.	0.8	0.5	5	5	2	1	3	3
Gastropods	0.04	0.04	0	0	1	1	0	0	0.7	0.5	0	0
Other	0.3	0.1	0.8	0.6	2	1	5	5	0	0	7	4
Total abundance (#/m²)	8885	1438	2548	521	2523	1268	156	66	3688	1278	729	205
Richness (# species/sample)	12	1.4	10	1.7	6	1.5	3	0.5	11	1.0	7	1.5
Shannon diversity (H')	0.78	0.13	1.26	0.09	1.03	0.24	0.81	0.23	1.24	0.18	1.53	0.15

	Inner Harbour – Site 02											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		5		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Composition – Major groups (%)												
Polychaetes	99	0.1	97	0.8	77	12	95	1	92	1	70	16
Cossura longocirrata	96	0.4	89	2	55	13	79	6	69	4	41	13
Other polychaetes	3	0.4	8	1	22	3	16	5	23	3	30	11
Nematodes	0.04	0.02	0.07	0.04	0.3	0.3	0	0	0.08	0.05	0.2	0.1
Bivalves	0.5	0.1	3	0.8	23	12	5	1	5	0.5	29	16
Nucula proxima	0.3	0.07	2	0.7	22	13	4	0.9	5	0.5	28	16
Other bivalves	0.2	0.06	0.6	0.1	0.7	0.2	0.7	0.4	0.9	0.5	1	0.2
Crustaceans	0.03	0.02	0.1	0.04	0.1	0.1	0	0	2	0.8	0.3	0.2
Gastropods	0.1	0.05	0.08	0.02	0.3	0.2	0.1	0.08	0.8	0.2	0.05	0.05
Other	0.03	0.02	0.1	0.08	0	0	0	0	0.03	0.03	0.1	0.1
Total abundance (#/m²)	36841	5760	45688	13019	11265	5488	14056	3766	12648	2890	9763	4398
Richness (# species/sample)	12	1.2	19	2.7	10	1.9	10	0.5	15	0.9	10	0.9
Shannon diversity (H')	0.25	0.02	0.57	0.09	1.10	0.14	0.78	0.18	1.20	0.12	1.13	0.19

Table B4. continued.

	Inner Harbour – Site 03											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		5		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Composition – Major groups (%)												
Polychaetes	99	0.2	95	3	93	4	97	0.8	86	6	89	4
Cossura longocirrata	93	0.9	73	9	86	4	79	5	62	10	69	7
Other polychaetes	6	0.8	22	6	7	1	18	5	24	8	19	4
Nematodes	0.01	0.01	0.2	0.1	4	3	0	0	0.03	0.03	3	2
Bivalves	1	0.1	3	2	4	1	3	0.5	12	6	6	1
Nucula proxima	0.4	0.07	1	0.6	3	1	2	0.4	11	6	5	1
Other bivalves	0.5	0.1	2	1	0.4	0.3	0.4	0.1	1	0.3	1	0.7
Crustaceans	0.03	0.01	1	0.6	0	0	0	0	1	0.5	1	0.5
Gastropods	0.1	0.05	0.2	0.2	0.04	0.04	0.3	0.2	0.5	0.2	0.2	0.09
Other	0.09	0.03	0.6	0.4	0.02	0.02	0.1	0.1	0.09	0.09	0.4	0.3
Total abundance (#/m²)	31355	2109	43259	12630	26393	8139	18785	5706	14698	2988	13819	5246
Richness (# species/sample)	15	1.1	20	2.4	12	0.9	12	0.7	18	1.4	14	0.6
Shannon diversity (H')	0.38	0.04	1.01	0.30	0.60	0.11	0.86	0.15	1.27	0.18	1.20	0.22

	Outer Harbour – Site 04											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		5		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Composition – Major groups (%)												
Polychaetes	70	4	74	5	81	7	51	15	47	8	78	5
Cossura longocirrata	25	4	16	6	18	6	3	2	2	0.9	18	6
Other polychaetes	45	3	58	5	63	8	48	14	46	7	60	5
Nematodes	0.3	0.2	0.1	0.1	0.9	0.6	0.1	0.1	0.8	0.2	5	1
Bivalves	26	3	23	5	17	7	47	15	50	8	14	5
Nucula proxima	14	2	15	4	12	5	40	14	36	7	11	4
Other bivalves	12	2	8	2	5	3	7	2	14	2	4	0.9
Crustaceans	2	0.6	1	0.7	0.3	0.2	0.7	0.5	1	0.3	1	0.6
Gastropods	0.3	0.09	1	0.5	0.4	0.4	0.4	0.3	0.2	0.2	0.9	0.6
Other	1	0.2	0.3	0.2	0.1	0.1	0.2	0.2	0.7	0.6	0.07	0.07
Total abundance (#/m²)	8171	885	3900	397	5190	887	3065	595	3433	426	8748	1513
Richness (# species/sample)	22	1.2	17	1.1	13	1.2	12	1.6	16	1.3	16	0.7
Shannon diversity (H')	2.16	0.08	2.08	0.06	1.74	0.11	1.54	0.17	1.86	0.09	1.86	0.02

Table B4. continued.

	Outer Harbour – Site 06											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		5		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Composition – Major groups (%)												
Polychaetes	28	3	43	9	45	6	40	6	42	6	43	6
Cossura longocirrata	2	0.6	2.2	2	5	2	2	0.4	0.7	0.7	3	1
Other polychaetes	27	3	41	8	40	6	38	6	41	6	40	5
Nematodes	0.3	0.2	0.3	0.3	0.8	0.4	0.6	0.5	0.7	0.7	4	2
Bivalves	63	4	35	10	49	5	35	6	31	4	43	6
Nucula proxima	56	4	29	8	42	5	28	6	25	5	38	6
Other bivalves	7	0.5	6	2	8	1	7	0.4	6	3	5	2
Crustaceans	6	3	13	3	4	1	22	3	18	4	8	1
Gastropods	0.8	0.2	4	1	0.2	0.2	2	0.4	8	3	1	0.5
Other	0.7	0.2	3	2	0.3	0.2	1	0.5	1	0.9	0.3	0.1
Total abundance (#/m²)	8056	1031	2430	280	4050	1019	5140	995	1259	278	5695	577
Richness (# species/sample)	23	1.6	21	2.7	16	1.9	22	3.7	15	1.4	21	2.0
Shannon diversity (H')	1.73	0.09	2.42	0.23	1.91	0.09	2.26	0.22	2.34	0.11	2.05	0.08

	Outer Harbour – Site 13											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n			5		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Composition – Major groups (%)												
Polychaetes	ns	-	62	5	40	5	43	6	39	3	28	4
Cossura longocirrata	ns	-	9	5	9	3	7	3	3	1	8	4
Other polychaetes	ns	-	53	9	31	4	35	6	36	4	20	3
Nematodes	ns	-	1	0.3	1	0.6	0.2	0.2	0	0	0.8	0.4
Bivalves	ns	-	34	6	56	5	56	6	57	4	70	5
Nucula proxima	ns	-	28	7	53	5	53	7	52	6	67	4
Other bivalves	ns	-	6	1	3	1	3	0.8	6	2	3	0.5
Crustaceans	ns	-	1	0.8	0	0	0.9	0.2	1	0.9	0.8	0.2
Gastropods	ns	-	0.3	0.2	1	0.9	0.3	0.2	2	1	0.3	0.1
Other	ns	-	1	0.8	2	0.9	0.3	0.3	0.6	0.2	0.2	0.1
Total abundance (#/m²)	ns	-	5863	2520	4492	824	4872	870	2872	893	6679	850
Richness (# species/sample)	ns	-	17	2.5	15	0.8	14	1.0	13	1.8	15	2.1
Shannon diversity (H')	ns	-	1.85	0.12	1.61	0.08	1.55	0.16	1.65	0.11	1.28	0.12

ns - Site 13 not sampled August 2011

APPENDIX C. Analysis of seasonal variation in benthic community

Table C-1. Seasonal variation between benthic communities at Inner and Outer Saint John Harbour reference sites.

Two-way ANOVA with date and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050.		
	Abundance (# individuals)	Richness (# species)
Site 13 data excluded because not sampled August 2011		
Transform	not improved	Log
Normality	Fail (<0.050)	Fail (<0.050)
Equal Variance	Fail (<0.050)	Pass (0.148)
Date	<0.001	<0.001
Site	<0.001	<0.001
Date x Site	0.006	<0.001
August 2011 data excluded because Site 13 not sampled		
Transform	not improved	None
Normality	Fail (<0.050)	Pass (0.179)
Equal Variance	Fail (<0.050)	Pass (0.318)
Date	0.004	<0.001
Site	<0.001	<0.001
Date x Site	0.007	0.085

Date within Site - Dates with different letters are significantly different						
Date	Abundance (# individuals)					
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Site 13 data excluded because not sampled August 2011						
Aug 2011	a	a	ab	a	a	-
Oct 2011	a	a	a	a	a	-
Apr 2012	a	b	ab	a	a	-
Jun 2012	a	b	b	a	a	-
August 2011 data excluded because Site 13 not sampled						
Aug 2011	-	-	-	-	-	-
Oct 2011	a	a	a	a	a	A
Apr 2012	a	b	b	a	a	A
Jun 2012	a	b	b	a	a	A

Table C-1. continued.

Date within Site - Dates with different letters are significantly different						
Date	Richness (# species)					
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Site 13 data excluded because not sampled August 2011						
Aug 2011	a	a	a	a	a	-
Oct 2011	a	b	a	ab	a	-
Apr 2012	b	a	a	ab	a	-
Jun 2012	c	a	a	b	a	-
August 2011 data excluded because Site 13 not sampled						
Aug 2011	-	-	-	-	-	-
Oct 2011	a	a	a	a	a	A
Apr 2012	ab	b	b	a	a	A
Jun 2012	b	b	b	a	a	A

Site within Date - Sites with different letters are significantly different								
Site	Abundance (# individuals)				Richness (# species)			
	Aug 2011	Oct 2011	Apr 2012	Jun 2012	Aug 2011	Oct 2011	Apr 2012	Jun 2012
Site 13 data excluded because not sampled August 2011								
Site 01	a	a	a	a	a	a	a	A
Site 02	b	b	ab	a	a	b	ab	B
Site 03	b	b	b	a	ab	b	b	Bc
Site 04	a	a	a	a	b	ab	b	Bc
Site 06	a	a	a	a	b	b	b	C
Site 13	-	-	-	-	-	-	-	-
August 2011 data excluded because Site 13 not sampled								
Site 01	-	a	a	a	-	a	a	A
Site 02	-	b	ab	a	-	b	ab	Ab
Site 03	-	b	b	a	-	b	ab	B
Site 04	-	a	ab	a	-	ab	ab	B
Site 06	-	a	a	a	-	b	b	C
Site 13	-	a	a	a	-	ab	b	B

Table C-2. Seasonal variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Shannon Diversity Index (H').

Two-way ANOVA with date and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050.	
Site 13 data excluded because not sampled August 2011	
Transform	not improved
Normality	Pass (0.082)
Equal Variance	Fail (<0.050)
Date	<0.001
Site	<0.001
Date x Site	<0.001
August 2011 data excluded because Site 13 not sampled	
Transform	None
Normality	Pass (0.328)
Equal Variance	Pass (0.614)
Date	0.04
Site	<0.001
Date x Site	0.096

Date within Site - Dates with different letters are significantly different						
Date	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Site 13 data excluded because not sampled August 2011						
Aug 2011	a	a	a	a	a	-
Oct 2011	a	ab	b	ab	b	-
Apr 2012	a	b	ab	ab	ab	-
Jun 2012	a	b	ab	b	b	-
August 2011 data excluded because Site 13 not sampled						
Aug 2011	-	-	-	-	-	-
Oct 2011	a	a	a	a	a	A
Apr 2012	a	a	a	a	a	A
Jun 2012	a	a	a	a	a	A

Site within Date - Sites with different letters are significantly different								
Site	Aug 2011	Oct 2011	Apr 2012	Jun 2012	Aug 2011	Oct 2011	Apr 2012	Jun 2012
	Site 13 data excluded because not sampled August 2011				*August 2011 data excluded because Site 13 not sampled*			
Site 01	a	a	a	a	-	ad	ad	A
Site 02	b	b	a	a	-	b	ab	A
Site 03	b	ab	a	a	-	ab	a	A
Site 04	c	c	b	b	-	c	bc	B
Site 06	d	c	b	c	-	c	c	C
Site 13	-	-	-	-	-	cd	cbd	B

Table C-3. PERMANOVA of seasonal variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Bray Curtis similarity matrices on square root transformed data.

Two-way PERMANOVA with date and site as factors using Bray Curtis similarity matrices						
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Site 13 data excluded because not sampled August 2011						
Date	3	17151	5717	7.0156	0.001	998
Site	4	86669	21667	26.589	0.001	996
Date x Site	12	36066	3005.5	3.6882	0.001	992
Residual	105	85564	814.9			
Total	124	2.3251×10^5				
August 2011 data excluded because Site 13 not sampled						
Date	2	6797.9	3398.9	3.3029	0.001	999
Site	5	68486	13697	13.31	0.001	996
Date x Site	10	22218	2221.8	2.159	0.001	997
Residual	72	74094	1029.1			
Total	89	1.716×10^5				

Average percent similarity between/within dates				
	Aug 2011	Oct 2011	Apr 2012	Jun 2012
Site 01				
Aug 2011	60	-	-	-
Oct 2011	44	51	-	-
Apr 2012	27	29	25	-
Jun 2012	12	17	22	31
Site 2				
Aug 2011	75	-	-	-
Oct 2011	69	72	-	-
Apr 2012	53	54	55	-
Jun 2012	67	62	63	74
Site 3				
Aug 2011	80	-	-	-
Oct 2011	63	65	-	-
Apr 2012	69	59	64	-
Jun 2012	72	61	68	75
Site 4				
Aug 2011	70	-	-	-
Oct 2011	60	65	-	-
Apr 2012	59	65	65	-
Jun 2012	53	57	57	57
Site 6				
Aug 2011	64	-	-	-
Oct 2011	47	49	-	-
Apr 2012	51	48	59	-
Jun 2012	54	49	58	62

Table C-3. continued.

Average percent similarity between/within dates				
	Aug 2011	Oct 2011	Apr 2012	Jun 2012
Site 13				
Aug 2011	-	-	-	-
Oct 2011	-	45	-	-
Apr 2012	-	54	65	-
Jun 2012	-	53	65	66

APPENDIX D. Analysis of interannual variation in benthic community

Table D-1. Interannual variation between benthic communities at Inner and Outer Saint John Harbour reference sites.

Two-way ANOVA with data and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050.

	Abundance (# individuals)		Richness (# species)	
	Oct 2011+2012	Jun 2012+2013	Oct 2011+2012	Jun 2012+2013
Transform	log	log	none	Squared
Normality	Pass (0.446)	Pass (0.257)	Pass (0.353)	Fail (<0.050)
Equal Variance	Pass (0.208)	Pass (0.257)	Pass (0.626)	Pass (0.060)
Date	0.003	0.048	0.017	0.454
Site	<0.001	<0.001	<0.001	<0.001
Date x Site	0.132	0.006	0.562	0.655

Date - Dates with different letters are significantly different

Date	Abundance (# individuals)	Richness (# species)
Oct 2011	a	a
Oct 2012	b	b
Jun 2012	-	a
Jun 2013	-	a

Site - Sites with different letters are significantly different

Site	Abundance (# individuals)	Richness (# species)	
	Oct 2011+2012	Oct 2011+2012	Jun 2012+2013
Site 01	a	a	a
Site 02	b	b	a
Site 03	b	b	a
Site 04	a	b	a
Site 06	a	b	b
Site 13	a	ab	a

Date within site - Dates with different letters are significantly different

Date	Abundance (# individuals)					
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Jun 2012	a	a	a	a	a	A
Jun 2013	b	a	a	b	a	A

Table D-1. continued.

Site within date - Sites with different letters are significantly different		
Site	Abundance (# individuals)	
	Jun 2012	Jun 2013
Site 01	a	a
Site 02	b	b
Site 03	b	b
Site 04	c	b
Site 06	bc	b
Site 13	bc	b

Table D-2. Interannual variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Shannon Diversity Index (H').

Two-way ANOVA with data and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050.		
	Oct 2011+2012	Jun 2012+2013
Transform	none	none
Normality	Pass (0.357)	Pass (0.317)
Equal Variance	Pass (0.316)	Pass (0.707)
Date	0.496	0.038
Site	<0.001	<0.001
Date x Site	0.068	0.040

Date - Dates with different letters are significantly different	
Date	Abundance (# individuals)
Oct 2011	a
Oct 2012	a

Site - Sites with different letters are significantly different	
Site	Oct 2011+2012
Site 01	a
Site 02	a
Site 03	a
Site 04	bc
Site 06	b
Site 13	c

Date within site - Dates with different letters are significantly different						
Date	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Jun 2012	a	a	a	a	a	A
Jun 2013	b	a	a	a	a	A

Site within date - Sites with different letters are significantly different		
Site	Abundance (# individuals)	
	Jun 2012	Jun 2013
Site 01	a	abc
Site 02	a	a
Site 03	a	ab
Site 04	b	bc
Site 06	c	c
Site 13	b	ab

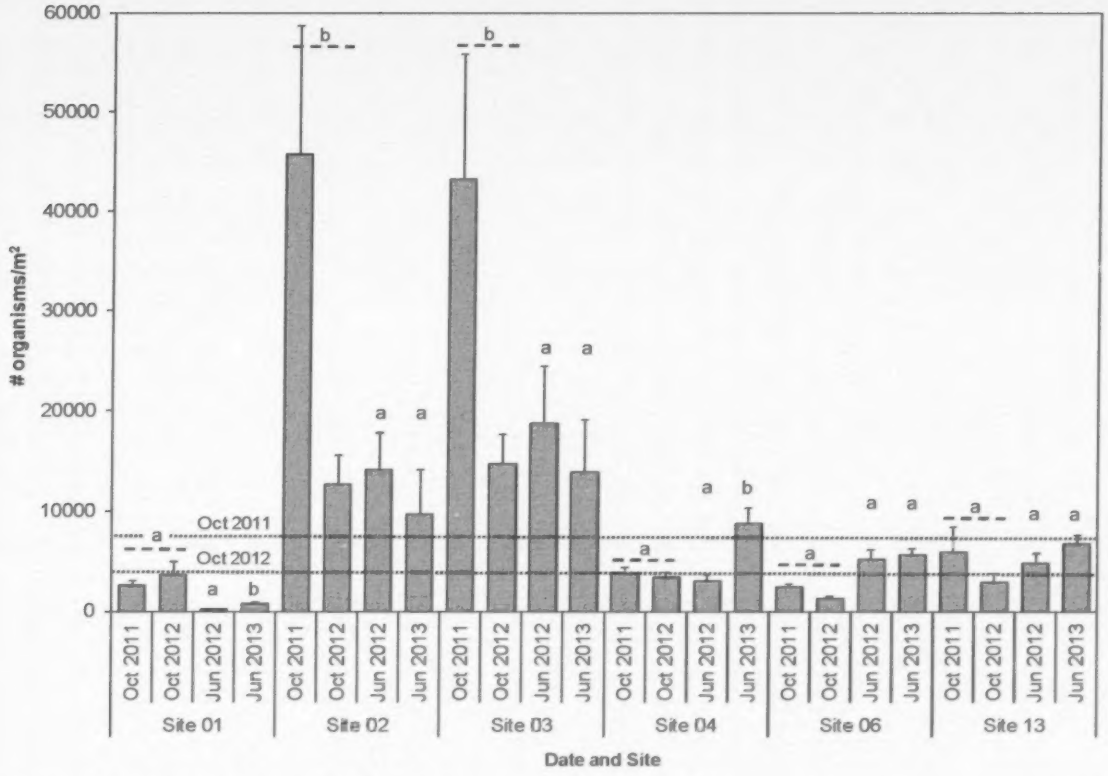


Figure D-1. Interannual variation of total organism abundance in sediments from Saint John Harbour reference sites, 2011-2013. Data are means (± SE) of n = 5 samples on each sampling date per site. Dotted lines are means across all sites that are significantly different. Different letters indicate significantly different means between sites for October 2011 and 2012 (dashed short lines) and between month-year pairing per site for June 2012 and 2013 (two-way ANOVA, Holm-Sidak test, $p < 0.050$).

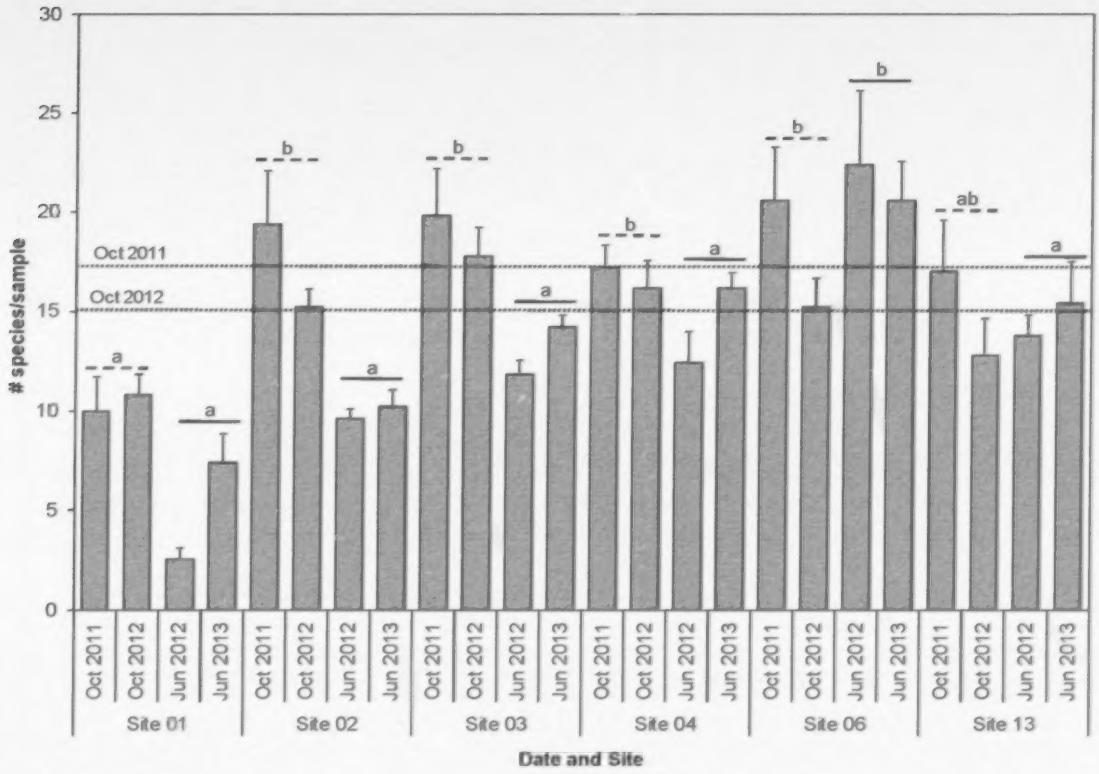


Figure D-2. Interannual variation of species richness in sediments from Saint John Harbour reference sites, 2011-2013. Data are means (± SE) of n = 5 samples on each sampling date per site. Dotted lines are means across all sites that are significantly different. Different letters indicate significantly different means between sites for October 2011 and 2012 (dashed short lines) and for June 2012 and 2013 (solid short lines; two-way ANOVA, Holm-Sidak test, $p < 0.050$).

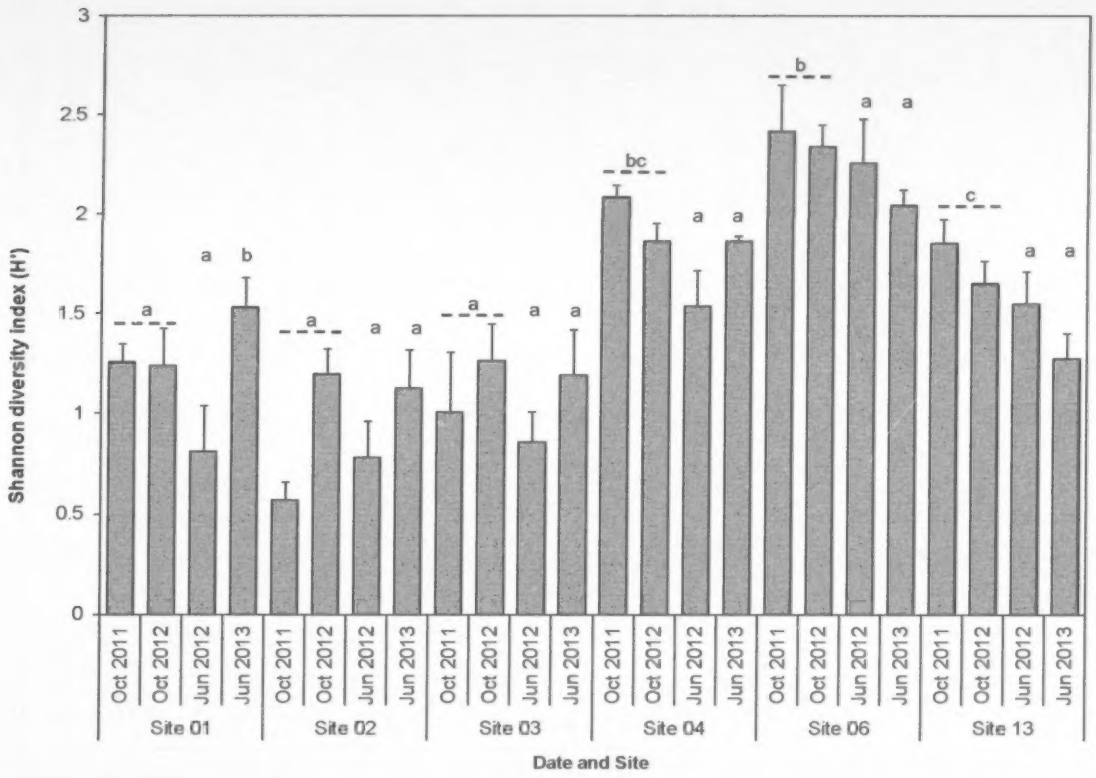


Figure D-3. Interannual variation of species diversity using Shannon diversity index (H') in sediments from Saint John Harbour reference sites, 2011-2013. Data are means (± SE) of n = 5 samples on each sampling date per site. Different letters indicate significantly different means between sites for October 2011 and 2012 (dashed short lines) and between month-year pairing per site for June 2012 and 2013 (two-way ANOVA, Holm-Sidak test, $p < 0.050$).

Table D-3. PERMANOVA of interannual variation between benthic communities at Inner and Outer Saint John Harbour reference sites using Bray Curtis similarity matrices on square root transformed data.

Two-way PERMANOVA with date and site as factors using Bray Curtis similarity matrices						
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Date	3	12273	4090.8	4.4751	0.001	999
Site	5	83415	16683	18.25	0.001	999
Date x Site	15	40318	2687.8	2.9403	0.001	996
Residual	96	87757	914.14			
Total	119	2.2376×10^5				

Average percent similarity between/within dates				
	Oct 2011	Jun 2012	Jun 2013	Oct 2012
Site 01				
Oct 2011	51	-	-	-
Jun 2012	17	31	-	-
Jun 2013	27	24	37	-
Oct 2012	42	14	31	55
Site 02				
Oct 2011	72	-	-	-
Jun 2012	62	74	-	-
Jun 2013	48	59	53	-
Oct 2012	62	71	57	76
Site 03				
Oct 2011	65	-	-	-
Jun 2012	61	75	-	-
Jun 2013	55	68	61	-
Oct 2012	58	70	63	66
Site 04				
Oct 2011	65	-	-	-
Jun 2012	57	56	-	-
Jun 2013	61	54	73	-
Oct 2012	59	59	56	60
Site 06				
Oct 2011	49	-	-	-
Jun 2012	49	62	-	-
Jun 2013	47	59	66	-
Oct 2012	50	42	41	53
Site 13				
Oct 2011	45	-	-	-
Jun 2012	53	66	-	-
Jun 2013	53	67	71	-
Oct 2012	49	58	57	54

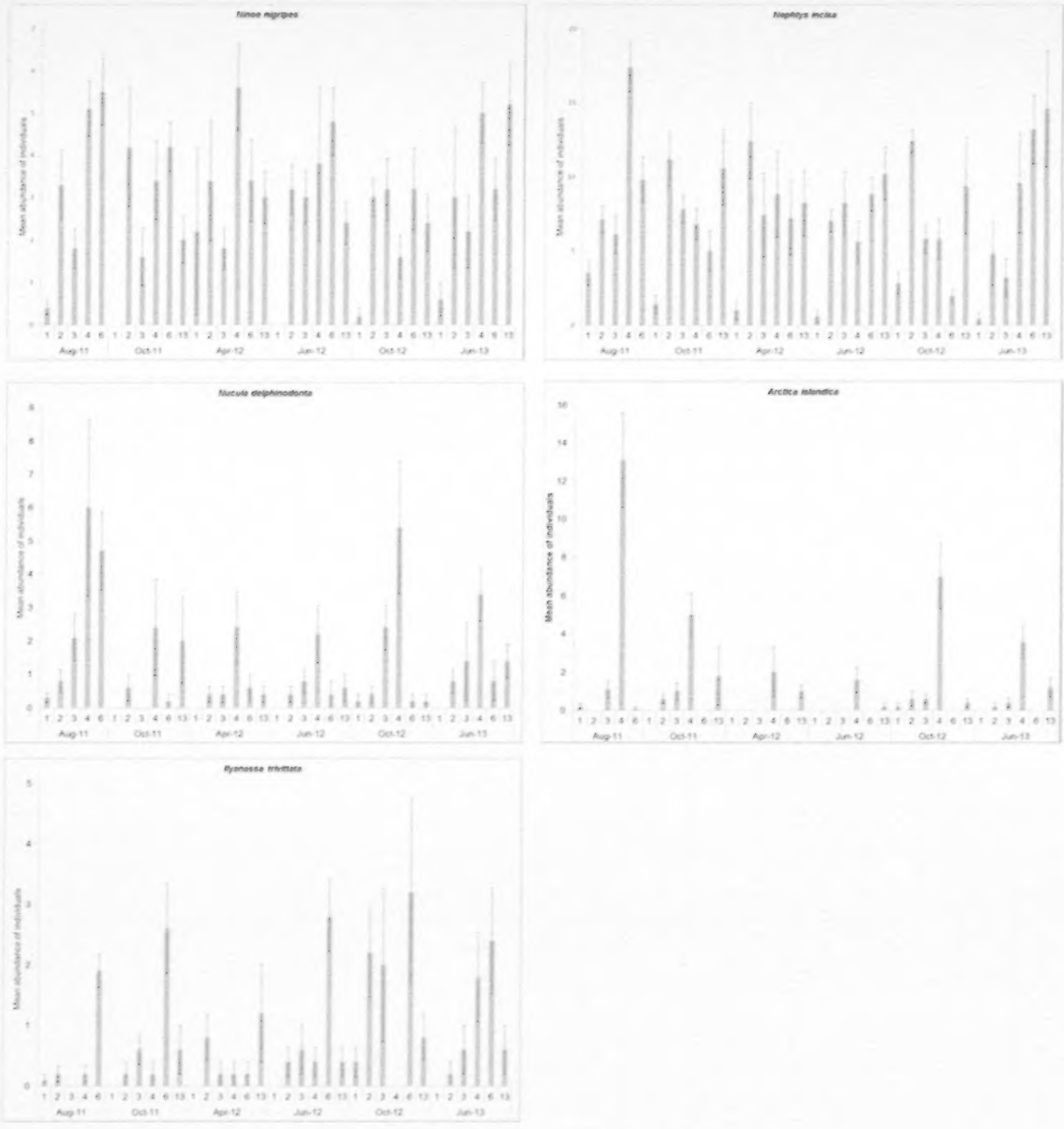


Figure D-4. Mean (+1SE) abundance of 2 species of polychaetes (*Ninoe nigripes* and *Nephtys incisa*), 2 bivalves (*Arctica islandica* and *Nucula delphinodonta*) and 1 gastropod (*Ilyanassa trivittata*) with dispersion (D) < 3.

APPENDIX E. Sediment physical/chemical data

Table E-1. Physical and chemical properties of sediment collected as surface grab samples from six Saint John Harbour references sites in 2011-2013.

	Inner Harbour – Site 01											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		10		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Physical Parameters (%)												
Moisture	40	2	29	3	30	6	38	6	37	4	40	2
TOC[a]	0.75	0.06	0.41	0.08	0.64	0.1	0.56	0.1	0.74	0.1	1.0	0.09
LOI_{550}	3.4	0.2	2.1	0.3	2.9	0.5	2.6	0.4	3.4	0.4	4.4	0.4
LOI_{950}	1.9	0.09	1.3	0.1	1.6	0.1	1.8	0.06	1.6	0.2	1.7	0.1
Silt-Clay	79	3	84	2	43	20	71	10	90	4	89	2
Fine-Med Sand	15	1	12	2	19	6	17	5	9.2	4	9.9	1.9
Coarse Sand	4.5	1	3.8	0.5	25	10	12	8	0.81	0.08	1.0	0.1
Gravel	1.5	0.6	0.53	0.07	13	6	0.66	0.2	0.24	0.05	0.063	0.04
Mz (mm)[b]	0.21	0.02	0.19	0.01	0.65	0.18	0.26	0.08	0.12	0.01	0.12	0.01
Metals and Organics (mg/kg dw)												
Al	18000	1000	12000	1000	20000	2000	21000	3000	11000	1000	20000	2000
As	7.1	0.5	5.2	0.4	8.7	0.9	8.0	0.9	6.1	0.4	6.7	0.3
Cd	0.059	0.02	0.077	0.01	0.13	0.02	0.12	0.02	0.062	0.006	0.089	0.002
Co	9.3	0.6	7.0	0.5	9.2	0.5	9.4	1.1	8.6	0.6	9.1	0.4
Cr	28	1	18	2	26	3	28	4	20	2	26	2
Cu	7.6	0.8	5.3	0.8	10	1	9.8	1.7	6.3	0.8	7.7	0.5
Fe	19000	1000	16000	900	22000	1000	23000	2000	21000	1000	22000	900
La	24	1	21	1	19	2	19	2	20	2	20	0.5
Mg	6200	300	4400	300	6800	500	6800	700	6000	400	6500	300
Mn	480	10	380	20	460	30	510	50	390	10	510	20
Ni	18	1	12	1	19	1	22	2	15	2	18	1
P	760	30	600	20	820	70	700	70	640	20	690	10
Pb	9.6	0.6	7.3	0.4	9.4	0.9	10	2	9.3	0.9	9.7	0.4
Rb	53	5	24	4	51	10	59	10	19	6	50	6
S	1600	200	1000	200	1600	500	1600	300	1700	200	1700	100
Se	1.4	0.1	1.0	0.2	0.46	0.09	0.44	0.1	2.8	0.09	0.50	0.09
Sr	49	2	34	3	49	4	52	6	42	2	50	3
V	41	2	28	2	39	3	46	6	35	2	43	3
Zn	50	4	34	3	53	5	51	7	42	4	48	2
Total Hg (µg/kg)	12	1	8.0	1	16	3	22	6	16	5	8.8	0.4
Total PAHs[c]	0.13	0.03	0.10	0.05	0.14	0.04	0.21	0.05	0.18	0.04	0.39	0.3
Total PCBs[d] (µg/kg)	na	-	6.4	1	na	-	na	-	na	-	na	-

Table E-1. continued.

	Inner Harbour – Site 02											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		6		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Physical Parameters (%)												
Moisture	45	0.5	45	1	31	2	38	3	40	2	43	2
TOC[a]	0.90	0.02	0.83	0.05	0.43	0.05	0.79	0.08	0.77	0.06	0.82	0.08
LOI_{550}	4.0	0.07	3.7	0.2	2.1	0.2	3.5	0.3	3.5	0.2	3.6	0.3
LOI_{950}	2.0	0.03	2.1	0.1	1.4	0.05	1.8	0.2	1.6	0.04	1.7	0.09
Silt-Clay	74	1	65	2	89	2	91	2	94	2	87	3
Fine-Med Sand	23	1	31	2	8.9	2.6	6.8	1.6	5.0	2.0	12	3
Coarse Sand	2.4	0.2	3.2	0.8	1.9	0.2	1.9	0.2	0.67	0.06	0.78	0.3
Gravel	0.57	0.04	0.37	0.07	0.52	0.08	0.54	0.08	0.16	0.03	0.072	0.02
Mz (mm)[b]	0.18	0.002	0.22	0.01	0.15	0.01	0.13	0.004	0.11	0.004	0.13	0.01
Metals and Organics (mg/kg dw)												
Al	23000	800	22000	700	17000	1000	19000	1000	12000	1000	22000	1000
As	8.0	0.1	7.2	0.2	5.8	0.3	6.7	0.4	6.6	0.7	7.1	0.5
Cd	0.060	0.01	0.085	0.01	0.061	0.02	0.103	0.007	0.054	0.008	0.067	0.01
Co	11	0.1	10	0.2	7.1	0.4	8.5	0.6	8.8	0.5	9.5	0.7
Cr	33	0.8	29	1	24	1	26	2	22	2	28	2
Cu	9.0	0.2	9.0	0.5	6.6	0.8	7.7	0.7	6.0	0.7	8.2	0.9
Fe	22000	400	26000	800	17000	800	20000	1000	22000	1000	26000	2000
La	21	0.4	21	0.5	22	2	20	0.6	19	1	22	1
Mg	7400	100	7200	200	4800	300	5900	400	6400	400	7100	300
Mn	530	6	480	10	440	20	430	20	360	20	510	30
Ni	21	0.2	19	0.5	16	1	19	2	16	1	18	2
P	670	9	670	20	670	40	730	30	630	4	690	30
Pb	11	0.1	11	0.3	6.6	0.5	8.5	0.7	9.0	0.7	10	1
Rb	75	3	61	3	50	4	55	6	27	5	58	5
S	2000	40	2100	90	1100	80	1600	200	1700	200	1900	100
Se	1.6	0.05	1.8	0.1	0.70	0.1	0.58	0.2	2.3	0.5	0.76	0.09
Sr	60	1	53	1	46	2	51	3	45	3	54	2
V	49	1	43	1	34	2	43	3	37	3	48	3
Zn	55	1	51	1	36	2	41	3	44	3	48	4
Total Hg (µg/kg)	11	1	12	1	6.1	0.6	13	2	11	1	9.7	1
Total PAHs[c]	0.29	0.05	0.24	0.04	0.12	0.01	0.29	0.2	0.12	0.02	0.073	0.03
Total PCBs[d] (µg/kg)	na	-	11	2	na	-	na	-	na	-	na	-

Table E-1. continued.

	Inner Harbour – Site 03											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		6		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Physical Parameters (%)												
Moisture	45	1	44	3	35	2	38	1	40	1	45	1
TOC[a]	0.90	0.09	0.87	0.1	0.76	0.08	0.77	0.03	0.75	0.04	1.2	0.07
LOI_{550}	4.0	0.3	3.8	0.4	3.4	0.3	3.5	0.1	3.4	0.1	5.1	0.3
LOI_{950}	1.9	0.06	2.3	0.1	1.5	0.08	1.8	0.06	1.8	0.06	1.9	0.05
Silt-Clay	66	2	73	4	91	1	86	3	87	3	86	2
Fine-Med Sand	30	2	25	4	8.2	1	11	2	12	3	13	2
Coarse Sand	2.6	0.3	1.3	0.2	0.54	0.07	2.3	0.4	0.98	0.3	1.2	0.5
Gravel	0.85	0.2	0.61	0.2	0.19	0.06	0.63	0.1	0.046	0.01	0.17	0.05
Mz (mm)[b]	0.23	0.01	0.18	0.01	0.13	0.002	0.15	0.01	0.12	0.01	0.14	0.01
Metals and Organics (mg/kg dw)												
Al	22000	1000	20000	2000	21000	2000	20000	1000	14000	1000	20000	2000
As	7.1	0.3	7.3	0.6	7.4	0.7	6.7	0.2	6.0	0.3	7.2	0.3
Cd	0.058	0.01	0.12	0.01	0.12	0.02	0.10	0.007	0.077	0.02	0.093	0.004
Co	10	0.3	9.7	0.6	9.1	0.8	8.8	0.4	9.1	0.6	9.6	0.4
Cr	31	1	28	2	29	3	27	1	24	1	26	1
Cu	8.1	0.4	4.1	1.1	9.5	0.9	7.6	0.5	6.3	0.3	9.6	0.6
Fe	23000	900	24000	2000	21000	2000	21000	800	23000	800	23000	800
La	25	1	19	1	26	3	22	1	20	1	18	0.5
Mg	7900	300	7100	500	5900	600	6000	300	6800	200	6800	300
Mn	480	10	440	30	500	50	430	4	370	8	490	20
Ni	18	1	20	1	19	2	18	1	16	1	19	1
P	710	10	640	30	750	60	800	10	610	30	730	10
Pb	10	0.4	11	1	9.4	0.9	9.0	0.5	8.9	0.3	11	0.4
Rb	60	4	56	8	61	8	59	5	30	3	51	5
S	1700	80	2100	200	1400	100	1500	100	1900	200	1900	70
Se	1.4	0.05	2.0	0.1	0.58	0.1	0.84	0.07	2.6	0.4	1.5	0.1
Sr	49	1	54	2	53	5	50	2	49	3	51	2
V	45	2	40	4	42	4	46	2	40	1	45	3
Zn	54	2	51	3	46	4	42	2	45	3	51	2
Total Hg (µg/kg)	13	1	15	2	9.7	0.6	11	2	10	0.3	11	0.8
Total PAHs[c]	0.16	0.06	0.27	0.07	0.19	0.02	0.12	0.03	0.15	0.007	0.10	0.01
Total PCBs[d] (µg/kg)	na	-	8.4	2	na	-	na	-	na	-	na	-

Table E-1. continued.

	Outer Harbour – Site 04											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		8		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Physical Parameters (%)												
Moisture	36	1	30	2	30	3	33	1	33	2	40	1
TOC[a]	0.57	0.04	0.41	0.03	0.58	0.09	0.48	0.04	0.51	0.04	0.72	0.04
LOI_{550}	2.7	0.1	2.0	0.1	2.7	0.4	2.3	0.2	2.4	0.2	3.3	0.1
LOI_{950}	1.5	0.1	1.4	0.1	1.1	0.1	1.5	0.07	1.4	0.03	1.6	0.05
Silt-Clay	80	1	73	3	86	1	72	4	79	3	77	2
Fine-Med Sand	18	1	25	3	13	1	24	4	21	3	22	2
Coarse Sand	1.5	0.2	1.1	0.2	0.59	0.3	2.7	0.5	0.50	0.1	0.83	0.1
Gravel	0.49	0.09	0.42	0.07	0.25	0.1	0.73	0.09	0.11	0.02	0.11	0.03
Mz (mm)[b]	0.17	0.003	0.17	0.003	0.14	0.004	0.18	0.01	0.14	0.004	0.14	0.01
Metals and Organics (mg/kg dw)												
Al	17000	800	14000	1000	17000	2000	17000	1000	12000	1000	26000	1000
As	5.7	0.2	5.2	0.2	5.8	0.3	5.9	0.3	4.8	0.3	6.3	0.3
Cd	0.083	0.01	0.066	0.01	0.049	0.01	0.12	0.01	0.04	0.01	0.13	0.01
Co	8.4	0.2	7.3	0.4	7.7	0.6	8.2	0.4	7.1	0.5	9.2	0.3
Cr	24	1	20	1	23	2	22	2	20	2	26	1
Cu	5.7	0.3	0.076	0.01	6.5	1.0	5.8	0.5	3.6	0.7	9.3	0.4
Fe	17000	400	18000	800	18000	1000	18000	800	19000	1000	29000	1000
La	21	1	19	1	21	1	20	1	20	2	26	1
Mg	5500	80	5000	300	4900	500	5020	300	5800	400	6300	200
Mn	420	20	370	10	470	6	[illegible]	10	330	20	440	20
Ni	15	1	14	1	15	2	16	1	11	1	18	1
P	610	20	480	20	560	20	530	40	460	30	580	40
Pb	8.2	0.2	7.6	0.4	7.9	0.6	9.1	0.4	7.5	0.6	11	0.4
Rb	44	3	32	4	48	8	44	5	20	6	50	3
S	1400	200	1100	100	1100	200	1200	100	1100	100	1600	90
Se	1.5	0.1	1.6	0.07	0.66	0.1	0.58	0.1	2.9	0.04	1.7	0.05
Sr	48	6	37	2	44	3	43	2	38	3	46	2
V	37	1	30	2	36	3	40	2	35	3.0	45	1
Zn	44	1	35	2	36	4	40	2	35	2.6	47	2
Total Hg (µg/kg)	7.3	0.5	5.7	0.6	5.9	1.0	5.9	0.7	7.2	0.7	8.1	0.5
Total PAHs[c]	0.09	0.02	0.04	0.01	0.22	0.06	0.10	0.03	0.10	0.03	0.11	0.02
Total PCBs[d] (µg/kg)	na	-	3.8	0.9	na	-	na	-	na	-	na	-

Table E-1. continued.

	Outer Harbour – Site 06											
date	Aug 2011		Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	10		7		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Physical Parameters (%)												
Moisture	31	1	29	1	30	1	31	1	30	1	32	2
TOC[a]	0.56	0.03	0.52	0.03	0.48	0.03	0.50	0.02	0.55	0.03	0.62	0.07
LOI_{550}	2.6	0.1	2.5	0.1	2.3	0.1	2.4	0.08	2.6	0.1	2.9	0.3
LOI_{950}	1.5	0.04	2.3	0.4	1.7	0.1	1.5	0.02	1.5	0.06	1.5	0.03
Silt-Clay	56	4	40	4	72	4	59	9	61	5	52	6
Fine-Med Sand	38	4	40	1	24	4	27	6	34	4	45	6
Coarse Sand	3.3	0.4	5.6	0.4	2.6	0.4	5.8	1	2.0	0.2	1.5	0.3
Gravel	2.8	0.4	15	4	2.1	1.0	7.7	3	3.1	1	0.76	0.3
Mz (mm)[b]	0.29	0.01	0.66	0.12	0.22	0.03	0.43	0.13	0.27	0.05	0.22	0.01
Metals and Organics (mg/kg dw)												
Al	15000	2000	21000	900	18000	800	19000	800	15000	1000	17000	2000
As	5.6	0.4	6.6	0.1	6.1	0.2	8.2	2	4.8	0.2	5.6	0.3
Cd	0.05	0.01	0.09	0.002	0.08	0.005	0.16	0.01	0.05	0.01	0.10	0.01
Co	9.1	0.4	9.5	0.3	8.1	0.4	9.0	0.4	8.2	0.5	8.6	0.4
Cr	22	1	26	1	24	1	24	1	22	2	21	1
Cu	6.1	0.9	0.36	0.2	7.2	0.3	6.3	0.3	4.8	0.5	7.2	1
Fe	21000	3000	25000	600	19000	700	18000	900	23000	1600	22000	2000
La	18	1	20	0.3	19	0.4	18	0.4	20	1.1	14	0.7
Mg	6300	600	6800	200	5300	200	5100	200	7400	500	5400	300
Mn	360	8	390	9	410	6	330	8	360	20	390	7
Ni	16	1	18	1	17	1	18	1	14	1	16	1
P	530	40	470	7	620	20	600	80	400	20	490	30
Pb	8.6	0.4	7.9	0.3	7.2	0.3	8.8	0.2	6.9	0.7	8.7	0.6
Rb	33	3	50	3	50	4	49	3	24	3	34	4
S	2300	400	2500	200	1700	300	1800	300	2500	200	2300	300
Se	1.4	0.2	1.9	0.09	0.80	0.03	0.6	0.1	2.9	0.08	0.92	0.3
Sr	37	2	53	7	48	1	53	2	43	4	43	2
V	33	1	40	1	36	1	43	2	38	2	39	2
Zn	46	3	45	1	40	2	47	2	40	3	42	2
Total Hg (µg/kg)	7.1	0.6	5.5	0.8	7.9	0.9	5.7	0.5	9.2	2	6.5	0.9
Total PAHs[c]	0.07	0.02	0.08	0.04	0.27	0.08	0.14	0.04	0.20	0.05	0.17	0.02
Total PCBs[d] (ug/kg)	na	-	2.9	0.8	na	-	na	-	na	-	na	-

Table E-1. continued.

	Outer Harbour – Site 13									
date	Oct 2011		Apr 2012		Jun 2012		Oct 2012		Jun 2013	
n	6		5		5		5		5	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Physical Parameters (%)										
Moisture	35	4	38	4	39	2	35	3	38	4
TOC[a]	0.73	0.1	0.90	0.2	0.49	0.05	0.68	0.07	0.71	0.1
LOI_{550}	3.3	0.5	4.0	0.6	2.4	0.2	3.1	0.3	3.2	0.5
LOI_{950}	2.1	0.3	1.5	0.2	3.0	0.3	1.7	0.2	1.6	0.1
Silt-Clay	68	4	74	2	64	4	73	4	74	3
Fine-Med Sand	29	4	24	2	28	3	26	4	25	3
Coarse Sand	2.3	0.5	1.6	0.2	4.9	0.6	0.46	0.2	0.76	0.1
Gravel	0.78	0.1	0.36	0.08	3.2	2	0.57	0.4	0.07	0.01
Mz (mm)[b]	0.20	0.01	0.16	0.005	0.29	0.08	0.16	0.01	0.14	0.01
Metals and Organics (mg/kg dw)										
Al	19000	3000	24000	2000	22000	2000	13000	1000	20000	3000
As	6.9	1	7.7	0.7	7.7	0.5	4.7	0.4	6.4	0.7
Cd	0.11	0.02	0.12	0.02	0.17	0.01	0.05	0.01	0.07	0.02
Co	9.5	1	10	1	11	0.7	7.3	0.6	9.9	0.8
Cr	26	3	32	3	28	3	21	2	27	3
Cu	5.1	3	11	1	9.0	1	4.2	0.9	8.6	1
Fe	22000	2000	23000	2000	20000	1000	21000	2000	22000	2000
La	21	1	21	1	19	1	23	1	17	0.5
Mg	6100	700	6700	600	5400	400	6900	700	6300	700
Mn	380	20	470	20	350	10	330	20	430	5
Ni	18	3	21	2	22	2	12	1	19	2
P	560	40	580	20	600	20	460	20	580	20
Pb	9.2	2	11	1	12	1	8.1	0.9	11	1
Rb	48	10	78	10	57	9	19	5	55	10
S	1900	500	2200	300	1900	200	1500	200	2400	400
Se	1.8	0.2	0.52	0.09	0.82	0.1	2.9	0.04	0.60	0.1
Sr	46	4	51	3	52	1	39	3	44	2
V	39	5	47	4	47	4	36	3	47	5
Zn	49	8	52	4	55	5	36	4	50	5
Total Hg (µg/kg)	8.8	3	12	2	11	2	8.7	1	10	1
Total PAHs[c]	0.10	0.04	0.25	0.05	0.22	0.09	0.16	0.06	0.19	0.03
Total PCBs[d](µg/kg)	na	-	4.5	1	na	-	na	-	na	-

na – not analyzed, [a] total organic carbon (TOC) calculated from loss on ignition at 550°C (LOI_{550})
[b] average grain size Mz = Σ ($f_i m_i$)/100, where m_i is the size of grade i (i.e., 4, 2, 1, 0.5, 0.25, 0.125, 0.063 mm) and f_i is its percentage, [c] sum of 16 individuals PAHs: acenaphthene, acenaphthylene, anthracene, benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[g,h,i]perylene, chrysene, dibenzo[a,h]anthracene, fluoranthene, fluorine, indeno[1,2,3-cd]pyrene, naphthalene, phenanthrene, pyrene and
[d] sum of 88 individual PCB congeners

APPENDIX F. Analysis of seasonal variation in sediment chemical concentrations

Table F-1. Seasonal variation between sediment concentrations for select chemical parameters at Saint John Harbour reference sites.

Two-way ANOVA with date and site as factors with Holm-Sidak post-hoc comparisons for all pairwise multiple comparisons. P-value reported, alpha = 0.050.

	As	Pb	Zn	Total PAHs
Site 13 data excluded because not sampled August 2011				
Transform	reciprocal	reciprocal	None work	None work
Normality	Pass (0.087)	Pass (>0.150)	Pass (0.095)	Fail (<0.050)
Equal Variance	Pass (0.132)	Fail (<0.050)	Pass (0.255)	Pass (0.883)
Date	0.047	<0.001	<0.001	0.568
Site	<0.001	0.002	<0.001	0.016
Date x Site	<0.001	<0.001	<0.001	0.033
August 2011 data excluded because Site 13 not sampled				
Transform	reciprocal	reciprocal	None work	None work
Normality	Pass (0.131)	Pass (>0.150)	Fail (<0.050)	Fail (<0.050)
Equal Variance	Pass (0.093)	Pass (0.148)	Pass (0.524)	Pass (0.809)
Date	0.010	0.028	0.611	0.177
Site	0.001	0.002	0.001	0.374
Date x Site	<0.001	<0.001	0.002	0.045

Date within site - Dates with different letters are significantly different

Date	As						Pb					
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Aug 2011	a	a	a	a	a	-	a	b	a	a	a	-
Oct 2011	b	a	a	a	a	a	b	b	a	a	a	a
Apr 2012	a	a	a	a	a	a	ab	a	a	a	a	a
Jun 2012	a	a	a	a	a	a	ab	ab	a	a	a	a
Date	Zn						Total PAHs					
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Aug 2011	a	a	a	a	a	-	a	a	a	a	a	-
Oct 2011	b	ab	a	a	a	a	a	a	a	a	a	a
Apr 2012	a	b	a	a	a	a	a	a	a	a	a	a
Jun 2012	a	ab	a	a	a	a	a	a	a	a	a	a

Table F-1. continued.

Site within date - Sites with different letters are significantly different

Site	As				Pb			
	Aug 2011	Oct 2011	Apr 2012	Jun 2012	Aug 2011	Oct 2011	Apr 2012	Jun 2012
Site 01	abc	a	a	a	ab	a	ab	a
Site 02	a	c	a	a	b	b	a	a
Site 03	ab	bc	a	a	ab	ab	ab	a
Site 04	bc	ab	a	a	a	ab	ab	a
Site 06	c	bc	a	a	ab	ab	ab	a
Site 13	-	abc	a	a	-	ab	b	a
Site	Zn				Total PAHs			
	Aug 2011	Oct 2011	Apr 2012	Jun 2012	Aug 2011	Oct 2011	Apr 2012	Jun 2012
Site 01	a	a	a	a	a	a	a	a
Site 02	a	a	a	a	a	a	a	a
Site 03	a	a	a	a	a	a	a	a
Site 04	a	a	a	a	a	a	a	a
Site 06	a	a	a	a	a	a	a	a
Site 13	-	a	a	a	-	a	a	a

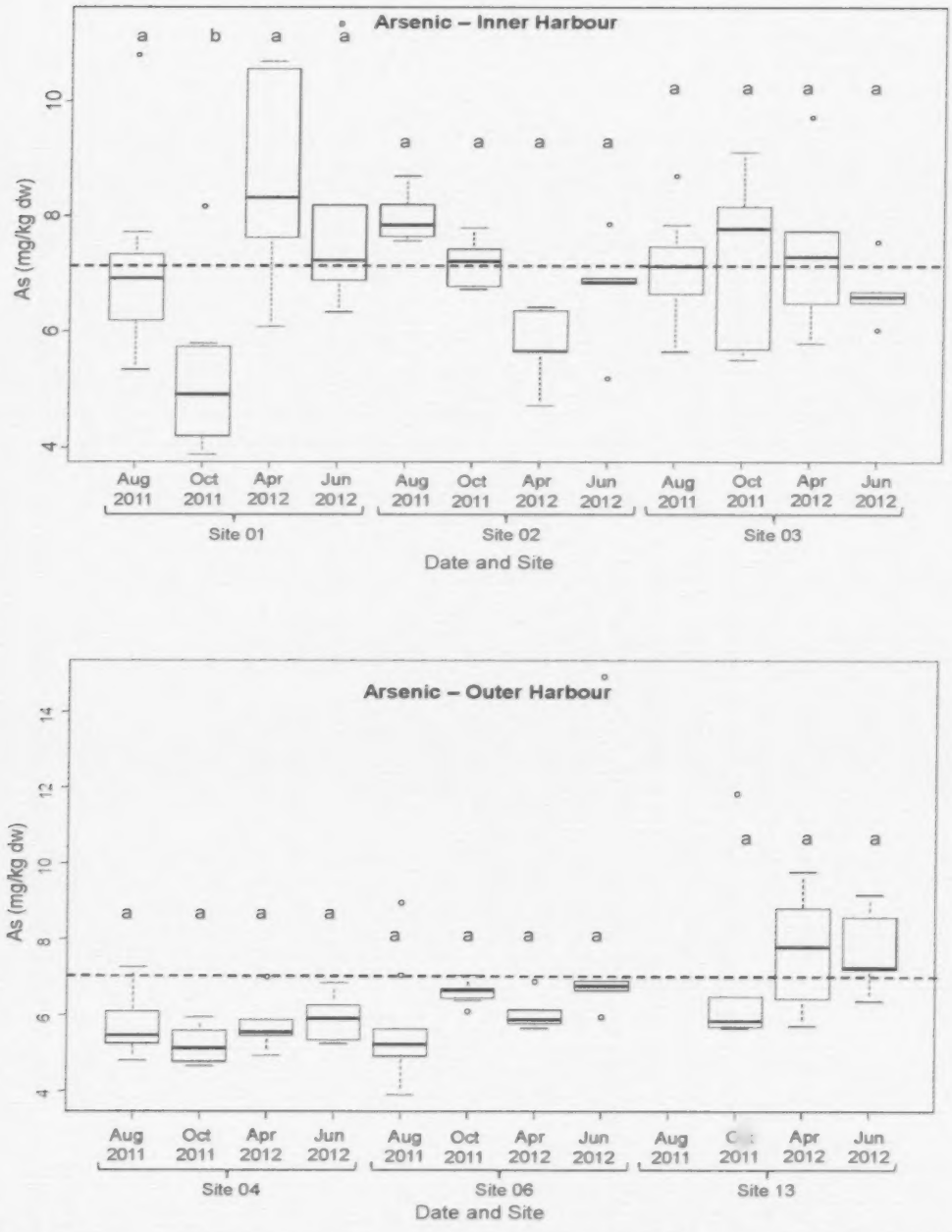


Figure F-1. Seasonal variation of arsenic concentrations in sediments from Saint John Harbour reference sites, 2011-2012. Dashed line is CCME-ISQG. Boxplot whiskers are minimum and maximum values. Different letters indicate significantly different mean concentrations within each site (two-way ANOVA, Holm-Sidak test, $p < 0.050$). n = 5-10 samples on each sampling date per site.

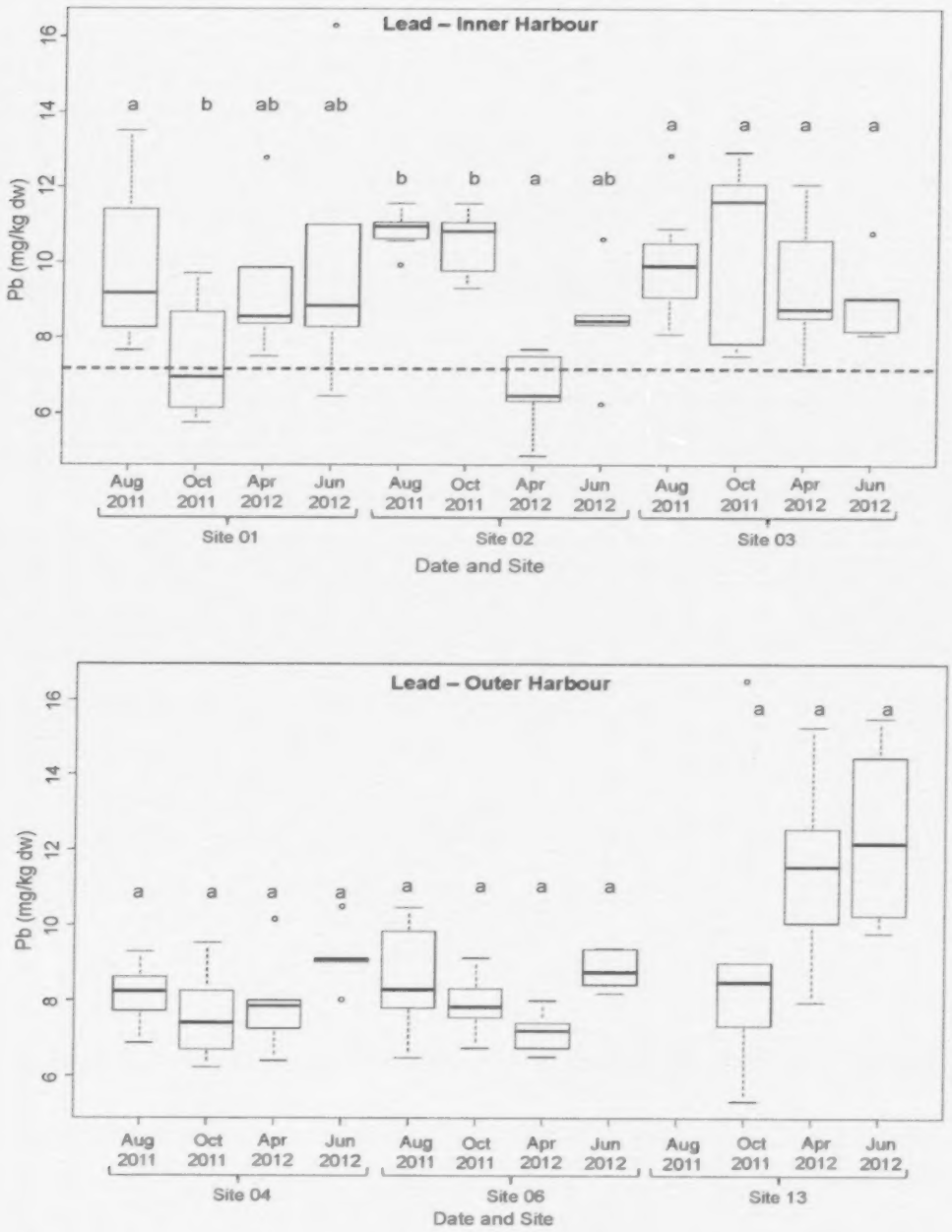


Figure F-2. Seasonal variation of lead concentrations in sediments from Saint John Harbour reference sites, 2011-2012. See Figure F-1 for description.

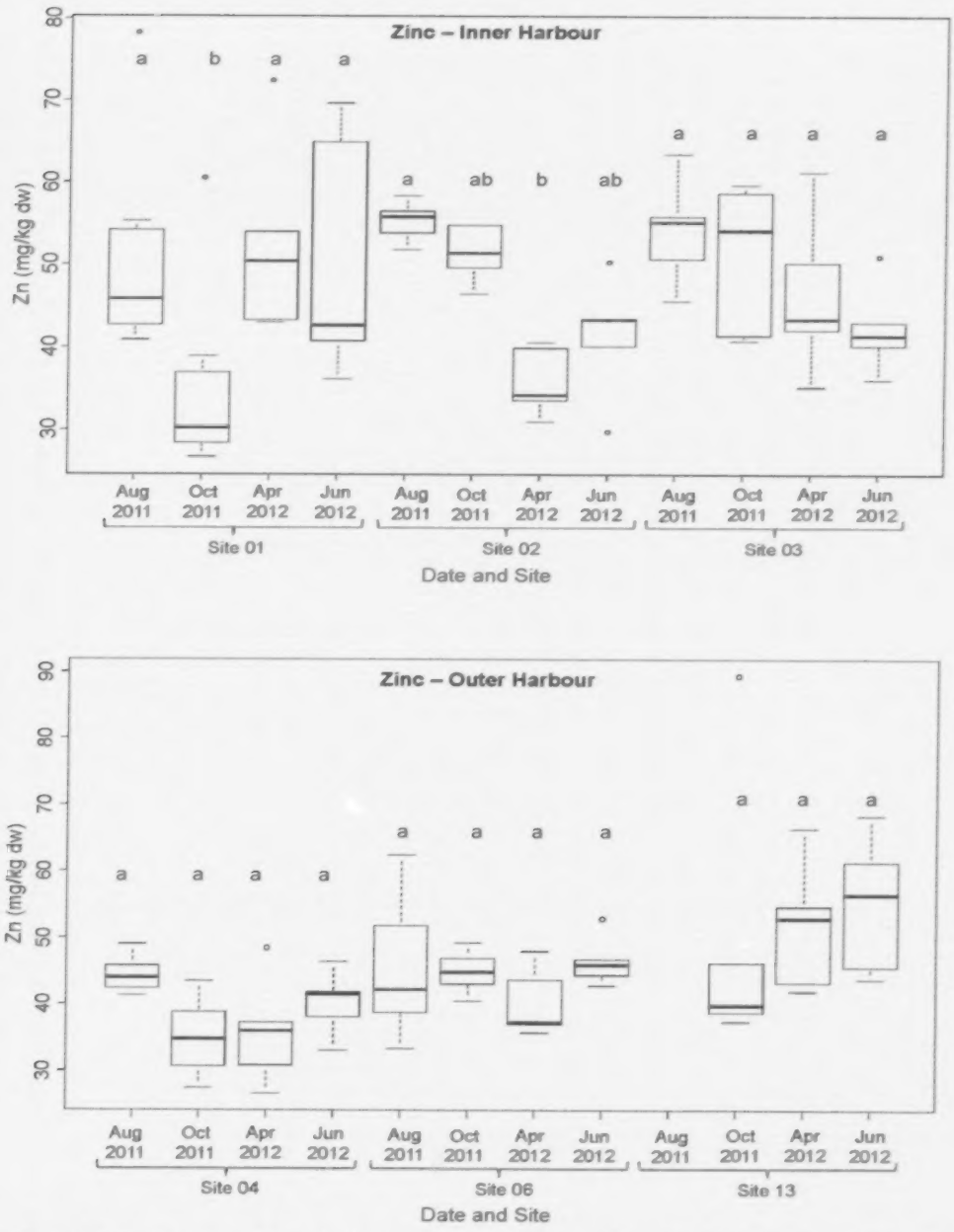


Figure F-3. Seasonal variation of zinc concentrations in sediments from Saint John Harbour reference sites, 2011-2012. See Figure F-1 for description.

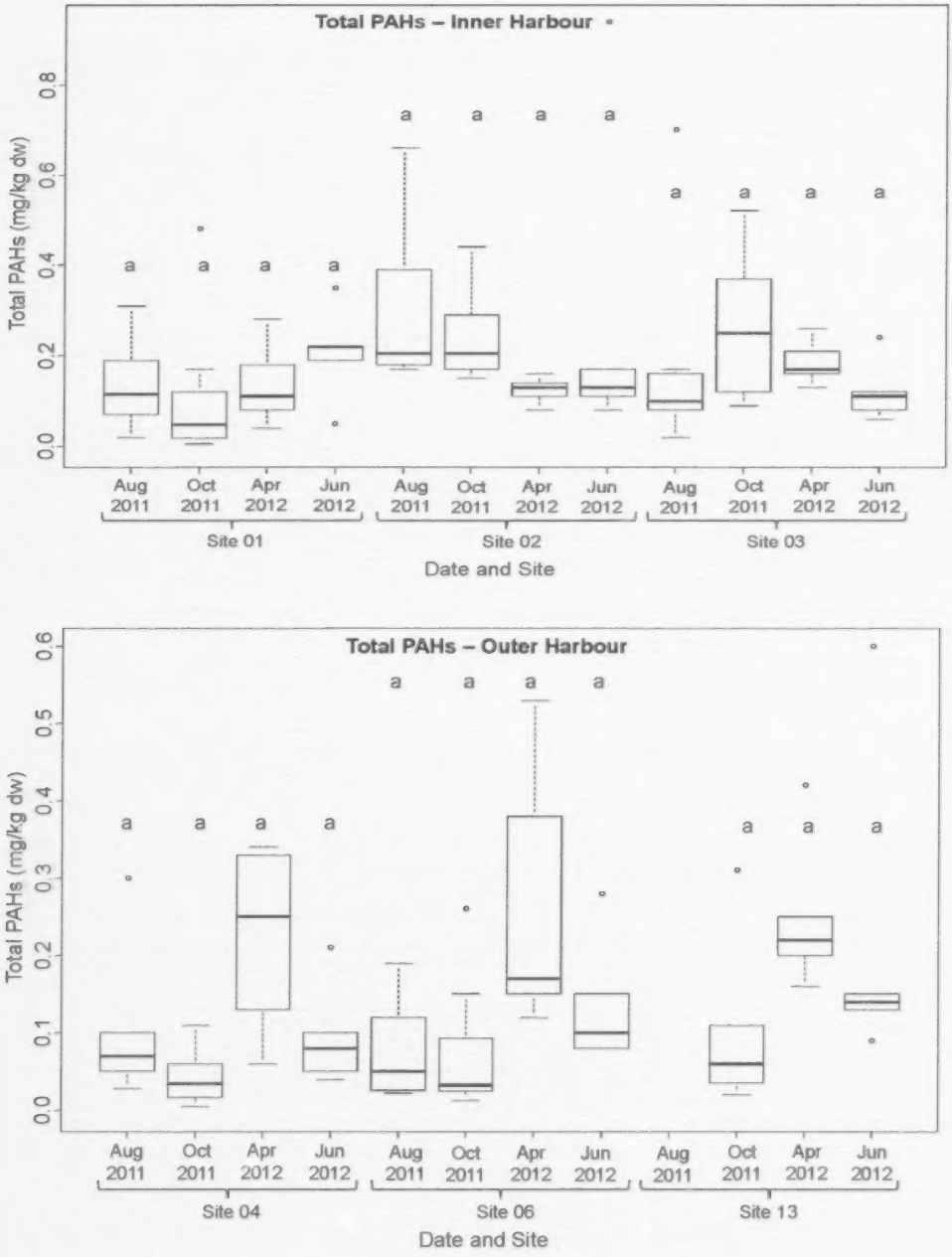


Figure F-4. Seasonal variation of total PAH in sediments from Saint John Harbour reference sites, 2011-2012. See Figure F-1 for description.

APPENDIX G. Analysis of interannual variation in sediment chemical concentrations

Table G-1. Interannual variation between sediment concentrations for select chemical parameters at Saint John Harbour reference sites.

Two-way ANOVA with date and site as factors with Holm-Sidak method for all pairwise multiple comparisons. P-value reported, alpha = 0.050.

	As	Pb	Zn	Total PAHs
October 2011 and 2012				
Transform	none work	log	reciprocal	none work
Normality	Fail (<0.050)	Pass (>0.150)	Pass (>0.150)	Fail (0.047)
Equal Variance	Pass (0.626)	Pass (0.543)	Pass (0.589)	Pass (0.050)
Date	0.002	0.240	0.150	0.008
Site	0.001	0.002	<0.001	0.009
Date x Site	0.018	0.087	0.025	0.012
June 2012 and 2013				
Transform	reciprocal	log	reciprocal	log
Normality	Pass (>0.150)	Pass (0.116)	Pass (0.106)	Pass (0.145)
Equal Variance	Pass (0.695)	Pass (0.169)	Pass (0.613)	Pass (0.761)
Date	0.080	0.297	0.220	0.465
Site	0.229	0.052	0.247	0.188
Date x Site	0.039	0.305	0.133	0.150

Date within site - Dates with different letters are significantly different

Date	As						Pb					
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13	All Sites					
Oct 2011	a	a	a	a	a	a	no posthoc test					
Oct 2012	a	a	a	a	a	a						
Date	Zn						Total PAHs					
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
Oct 2011	a	a	a	a	a	a	a	a	a	a	a	a
Oct 2012	a	a	a	a	a	a	a	a	a	a	a	a

Table G-1. continued

Site within date - Sites with different letters are significantly different

Site	As		Pb	Zn		Total PAHs	
	Oct 2011	Oct 2012	All Dates	Oct 2011	Oct 2012	Oct 2011	Oct 2012
Site 01	b	ab	abc	b	a	b	a
Site 02	ab	ab	a	a	a	a	a
Site 03	a	ab	ab	a	a	a	a
Site 04	ab	ab	bc	b	a	b	a
Site 06	ab	ab	c	ab	a	ab	a
Site 13	ab	b	abc	ab	a	ab	a

June Comparisons.

Date within site - Dates with different letters are significantly different

Date	As						Pb
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13	All Sites
Jun 2012	a	a	a	a	a	a	no posthoc test
Jun 2013	a	a	a	a	a	a	

Date	Zn	Total PAHs
	All Sites	All Sites
Jun 2012 Jun 2013	no posthoc test	no posthoc test

Site within date - Sites with different letters are significantly different

Site	As		Pb	Zn	Total PAHs
	Jun 2012	Jun 2013	All Dates	All Dates	All Dates
Site 01	a	a	no posthoc test	no posthoc test	no posthoc test
Site 02	a	a			
Site 03	a	a			
Site 04	a	a			
Site 06	a	a			
Site 13	a	a			

Table G-1. continued

Date within site - Dates with different letters are significantly different

Date	As						Pb
	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13	All Sites
Jun 2012	a	a	a	a	a	a	no posthoc test
Jun 2013	a	a	a	a	a	a	

Date	Zn	Total PAHs
	All Sites	All Sites
Jun 2012 Jun 2013	no posthoc test	no posthoc test

Site within date - Sites with different letters are significantly different

Site	As		Pb	Zn	Total PAHs
	Jun 2012	Jun 2013	All Dates	All Dates	All Dates
Site 01	a	a	no posthoc test	no posthoc test	no posthoc test
Site 02	a	a			
Site 03	a	a			
Site 04	a	a			
Site 06	a	a			
Site 13	a	a			

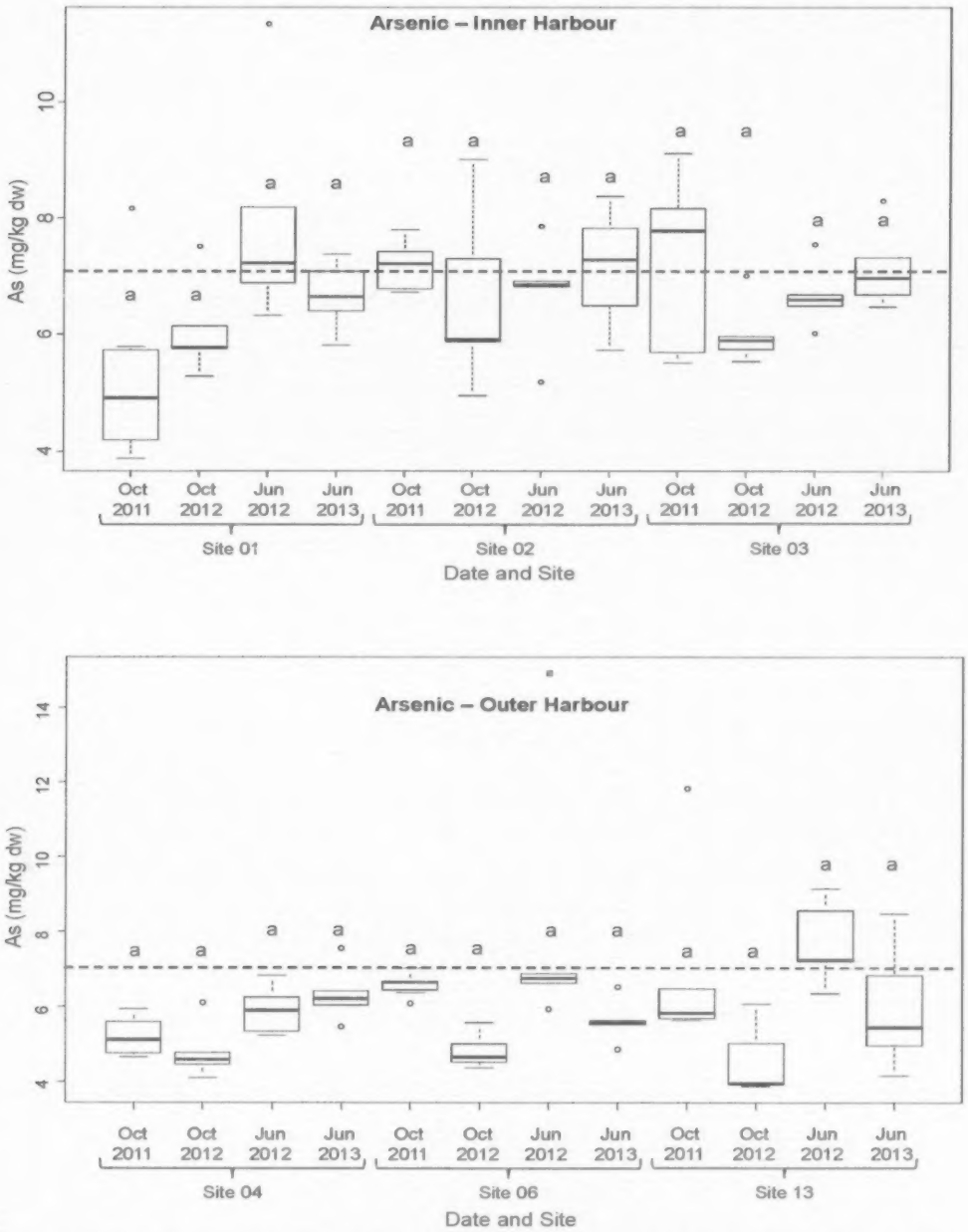


Figure G-1. Interannual variation of arsenic concentrations in sediments from Saint John Harbour reference sites, 2011-2013. Dashed line is CCME-ISQG. Boxplot whiskers are minimum and maximum values. Different letters indicate significantly different mean concentrations between month-year pairing per site (two-way ANOVA, Holm-Sidak test, $p < 0.050$). n = 5-10 samples on each sampling date per site.

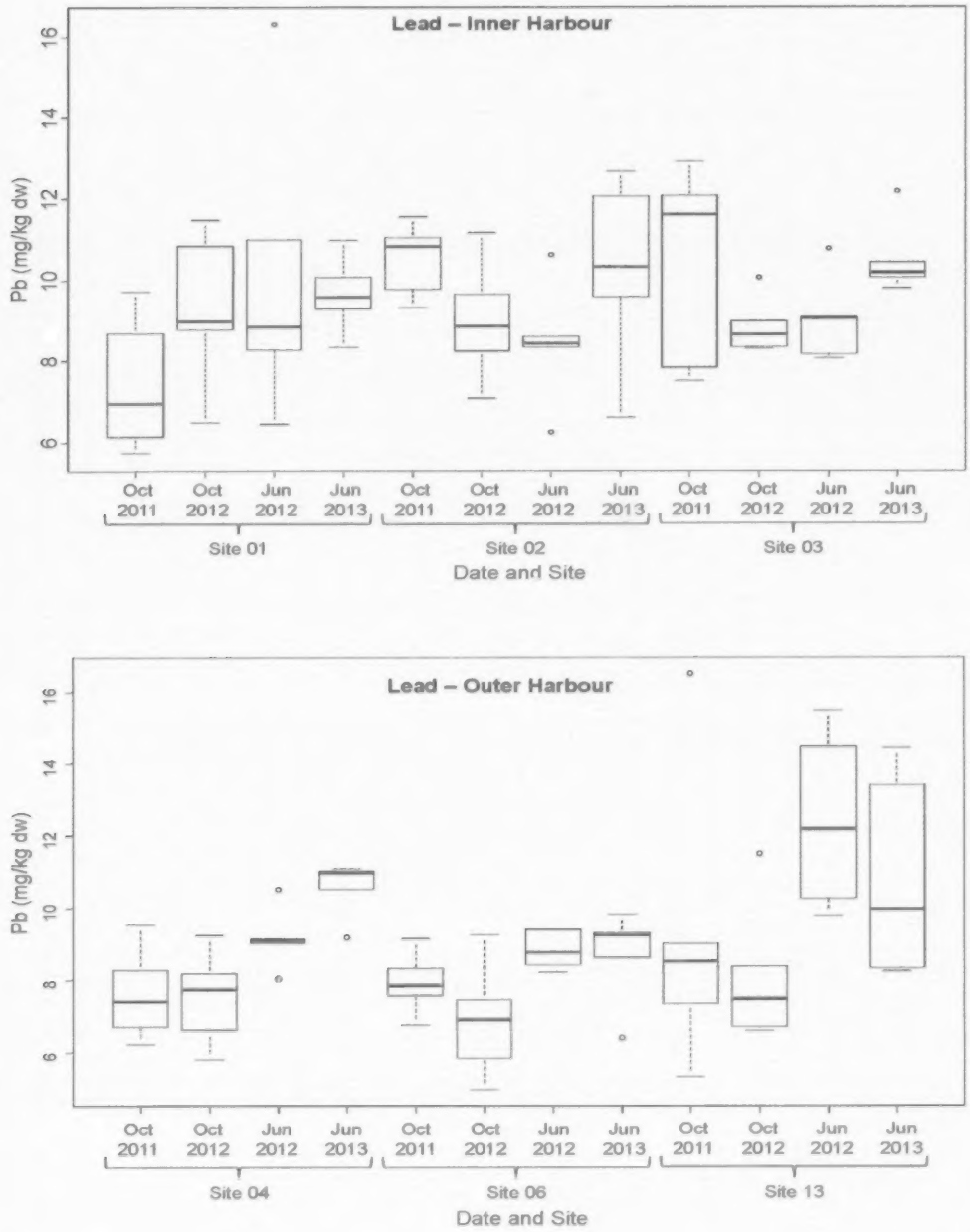
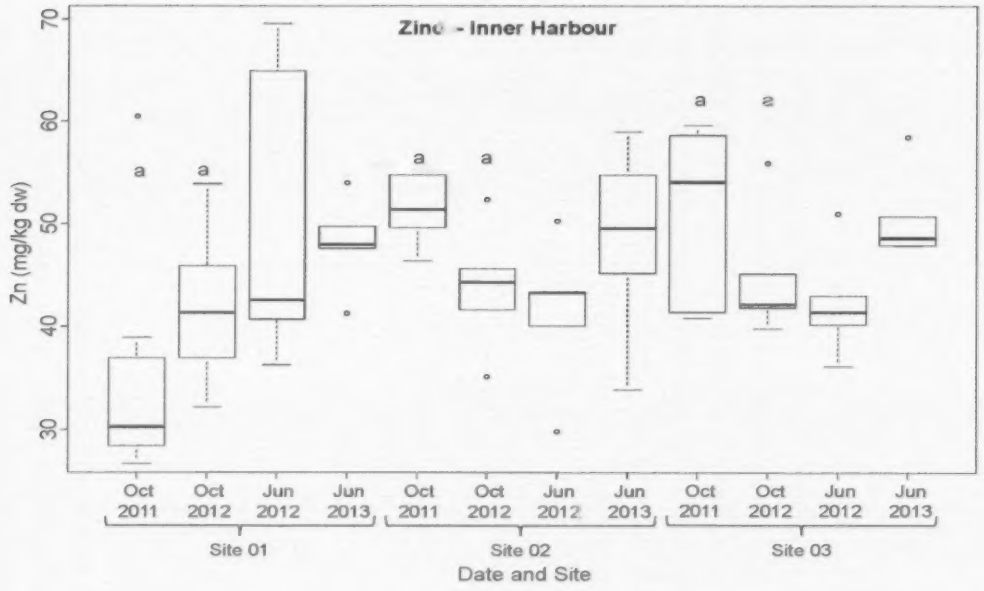


Figure G-2. Interannual variation of lead concentrations in sediments from Saint John Harbour reference sites, 2011-2013. See Figure G-1 for description.



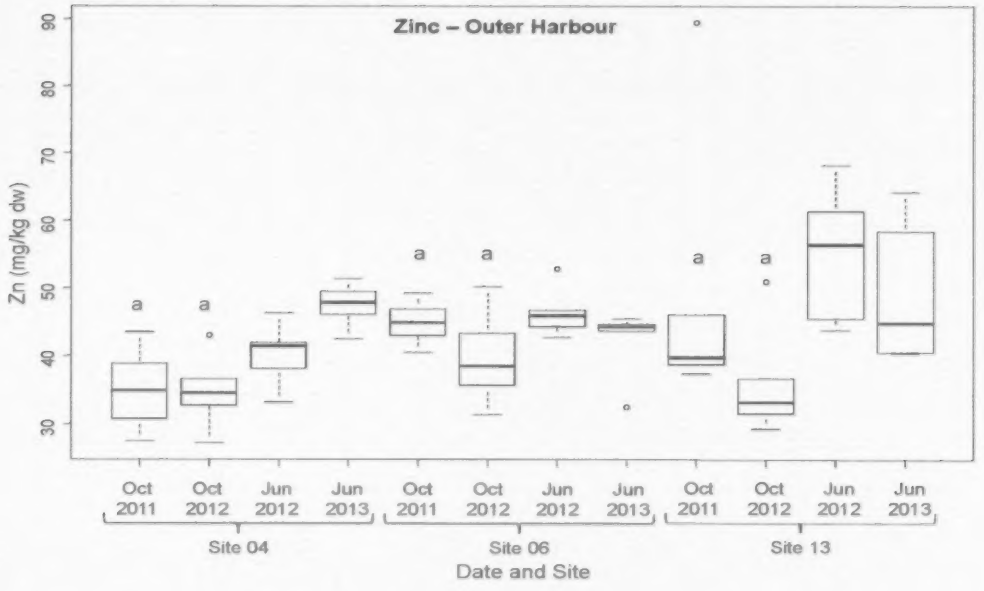


Figure G-3. Interannual variation of zinc concentrations in sediments from Saint John Harbour reference sites, 2011-2013. See Figure G-1 for description.

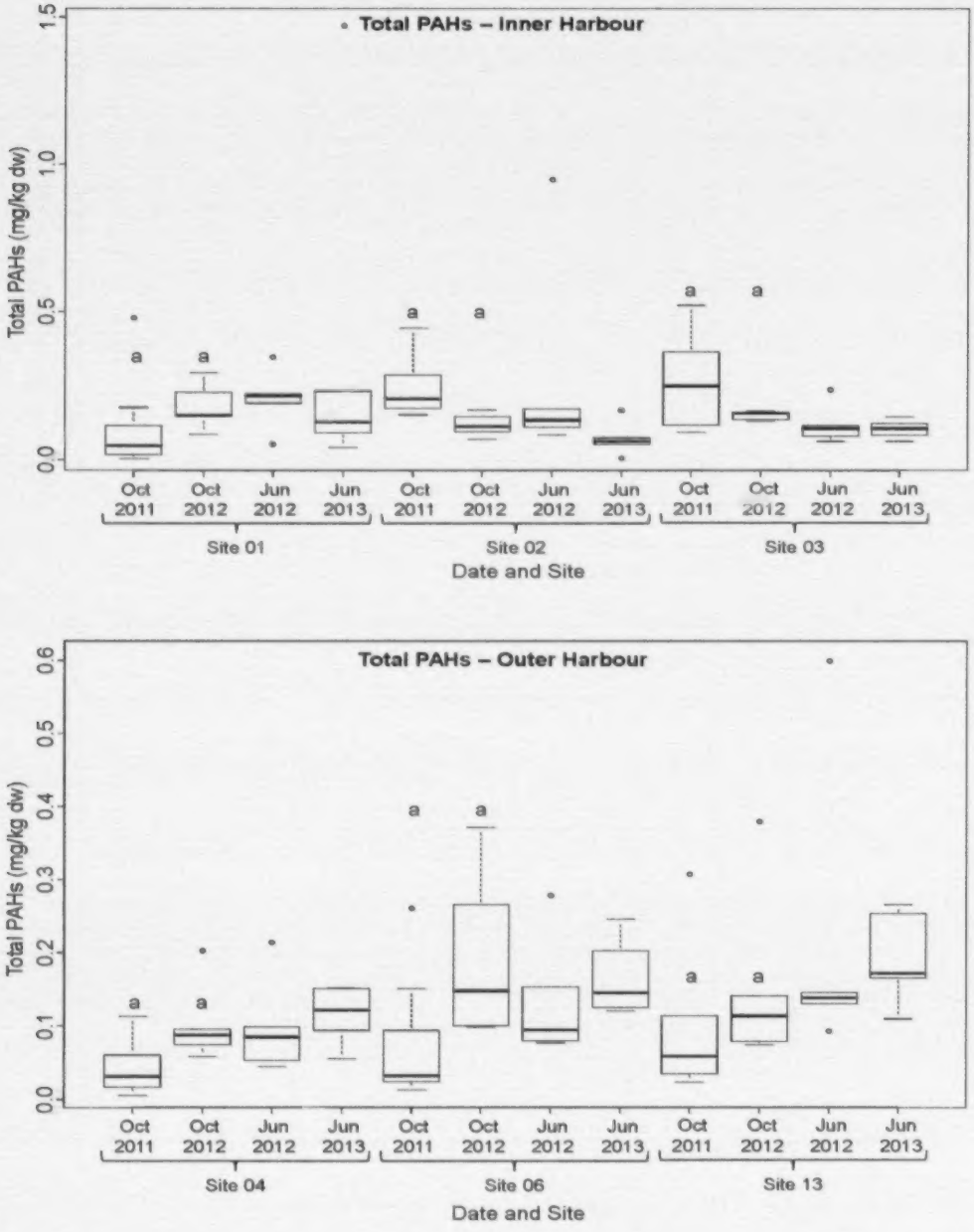


Figure G-4. Interannual variation of zinc concentrations in sediments from Saint John Harbour reference sites, 2011-2013. See Figure G-1 for description.

APPENDIX H. Taxonomic sufficiency

Table H-1. Taxonomic sufficiency, using second-stage MDS. Abundances were aggregated to the levels of species, genus, family, suborder, order, infraclass and class (note that many polychaetes worms are not classified to orders but to infraclass) and untransformed or transformed (square-root, logarithmic or presence/absence). Correlations (ρ_s) are expressed as the correlation between the similarity matrix for the species level for a given transformation to that of each of the taxonomic resolutions.

Interannual comparison – October 2011 and 2012

Spearman's Rank Correlation (ρ_s)	Species	Genus	Family	Suborder	Order	Infraclass	Class
Untransformed	1	0.99887	0.99590	0.93654	0.92968	0.92027	0.85222
Square-root	1	0.99306	0.98266	0.90896	0.87793	0.80671	0.72132
Logarithmic	1	0.99168	0.98117	0.90923	0.88007	0.81336	0.67498
Presence/Absence	1	0.96685	0.91504	0.75038	0.66536	0.39284	0.28297

Interannual comparison – June 2012 and 2013

Spearman's Rank Correlation (ρ_s)	Species	Genus	Family	Suborder	Order	Infraclass	Class
Untransformed	1	0.99958	0.99672	0.98238	0.9821	0.98039	0.95391
Square-root	1	0.99603	0.99248	0.9634	0.95772	0.939	0.90827
Logarithmic	1	0.99465	0.99009	0.94908	0.93967	0.90903	0.8758
Presence/Absence	1	0.97177	0.95418	0.86613	0.85154	0.75404	0.48178

Seasonal comparison for all sites without Aug. 2011

Spearman's Rank Correlation (ρ_s)	Species	Genus	Family	Suborder	Order	Infraclass	Class
Untransformed	1	0.99931	0.99655	0.95567	0.95433	0.95193	0.91331
Square-root	1	0.99589	0.99051	0.94744	0.93685	0.90257	0.85494
Logarithmic	1	0.99370	0.98690	0.93684	0.92329	0.87639	0.81425
Presence/Absence	1	0.97312	0.94391	0.83993	0.80985	0.61204	0.40090

Seasonal comparison for all 4 dates without site 13

Spearman's Rank Correlation (ρ_s)	Species	Genus	Family	Suborder	Order	Infraclass	Class
Untransformed	1	0.99927	0.99568	0.95532	0.95297	0.94923	0.90211
Square-root	1	0.9961	0.98993	0.94587	0.93052	0.89059	0.83376
Logarithmic	1	0.99516	0.98859	0.94237	0.92630	0.88226	0.80872
Presence/Absence	1	0.97539	0.94508	0.82977	0.79969	0.62208	0.41639

APPENDIX I. Range of reference concentrations for metals and PAHs

Table I-1. Range of reference concentrations for metals and PAHs (± 2x SD of the grand mean) on the basis of site, area (Inner-Sites 01, 02, 03 vs Outer-Sites 04, 06, 13), and region (whole harbour) in sediment collected from reference sites in Saint John Harbour, 2011-2013.

Metals and Organics (mg/kg dw)	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
n	6	6	6	6	6	5
Al	8000-25000	11000-27000	14000-25000	8100-26000	12000-22000	11000-27000
As	4.4-9.5	5.4-8.4	5.9-8	4.5-6.7	3.8-8.5	4.2-9.2
Cd	0.03-0.15	0.03-0.11	0.05-0.15	0.01-0.16	0.01-0.17	0.01-0.19
Co	6.9-11	6.5-12	8.4-10	6.4-9.5	7.6-9.9	6.9-12
Cr	16-33	19-35	22-32	17-28	19-27	18-35
Cu	3.9-12	5.3-10	3.4-12	0-11	0.1-11	1.9-13
Fe	15000-26000	15000-29000	19000-25000	11000-28000	16000-26000	20000-24000
La	17-24	18-24	15-28	18-23	14-23	15-25
Mg	4300-7900	4500-8500	5200-8300	4300-6500	4200-7900	5500-7200
Mn	340-560	340-580	350-550	290-500	310-430	280-510
Ni	10-24	14-22	16-21	10-19	13-20	11-26
P	540-860	610-750	560-850	420-660	350-690	440-670
Pb	7.2-11	6-13	8.2-11	6.1-11	6.4-9.7	6.9-14
Rb	9.3-76	23-86	30-76	17-63	18-62	9.3-94
S	1000-2100	1000-2400	1300-2300	830-1700	1500-2900	1200-2700
Se	0-3	0-2.7	0.02-3	0-3.2	0-3.1	0-3.4
Sr	33-60	41-62	47-55	34-52	33-59	35-57
V	26-52	31-54	38-48	27-47	31-45	33-54
Zn	32-60	32-60	39-57	29-50	38-49	34-63
THg	3.4-24	5.6-15	7.6-15	4.7-8.6	4.2-9.8	7.4-13
TPAHs	0-0.4	0-0.38	0.05-0.28	0-0.23	0-0.3	0.07-0.3

Table I-1. continued.

Metals and Organics (mg/kg dw)	Inner Harbour	Outer Harbour	Whole Harbour
n	18	17	35
Al	11000-26000	11000-25000	11000-25000
As	5.2-8.6	4-8.2	4.5-8.6
Cd	0.03-0.14	0.01-0.17	0.02-0.15
Co	7.2-11	6.6-11	6.9-11
Cr	19-34	17-31	18-33
Cu	4.3-11	0.5-11	1.9-11
Fe	16000-27000	15000-27000	16000-27000
La	17-25	16-24	16-25
Mg	4700-8200	4400-7400	4500-7900
Mn	350-560	300-480	300-540
Ni	13-22	11-22	12-22
P	570-820	400-670	410-820
Pb	7.2-12	5.7-12	6.4-12
Rb	20-80	14-73	17-77
S	1100-2300	770-2800	910-2600
Se	0-2.8	0-3.1	0-3
Sr	39-61	34-56	36-59
V	31-52	29-49	30-51
Zn	35-59	31-56	33-58
THg	4.8-19	3.9-11	2.5-17
TPAHs	0.01-0.35	0-2.8	0-1.9

APPENDIX J. Range of reference conditions for benthic invertebrates

Table J-1. Range of reference conditions (± 2 x SD of the grand mean) for total abundance, richness and diversity for benthic invertebrates on the basis of site, area (Inner-Sites 01, 02, 03 vs Outer-Sites 04, 06, 13), and region (whole harbour) in marine invertebrates collected from reference sites in Saint John Harbour, in October 2011 and 2012.

	Site 01	Site 02	Site 03	Site 04	Site 06	Site 13
n	5	5	5	5	5	5
Total abundance (m^{-2})	1505.46-4726.29	-17535.50-75809.40	-11360.30-69273.27	3008.61-4311.42	211.36-3486.00	115.28-8636.39
Species richness	9.27-11.53	11.54-22.86	17.30-20.70	15.47-17.73	11.03-25.17	8.96-20.84
Diversity	1.22-1.27	-0.01-1.78	0.74-1.56	1.67-2.27	2.33-2.45	1.45-2.07

	Inner Harbour	Outer Harbour	Whole Harbour
n	15	15	30
Total abundance (m^{-2})	-8056.51-48862.38	1111.75-5477.94	-3472.38-27170.16
Species richness	13.46-17.61	11.82-21.25	12.64-19.43
Diversity	0.67-1.52	1.82-2.26	1.47-1.67

APPENDIX K. Certified reference material recoveries

Table K-1. Mean ± standard deviation of CRM recoveries for THg, various elements and PAHs for SJH reference sites from August 2011 to June 2013.

	CRM 2702	CRM 1941b
TPAHs	-	88.2 ± 15.1
TPCBs	-	98.9 ± 28.4
THg	91.6 ± 4.6	-
Ag	<DL	-
Al	53.7 ± 3.4	-
As	78.0 ± 6.5	-
Cd	100.6 ± 28.4	-
Co	87.2 ± 6.8	-
Cr	74.6 ± 13.1	-
Cu	88.3 ± 6.6	-
Fe	73.2 ± 5.9	-
La	57.6 ± 8.0	-
Mg	69.0 ± 3.8	-
Mn	82.0 ± 4.5	-
Ni	81.1 ± 7.0	-
P	89.4 ± 11.5	-
Pb	78.2 ± 6.5	-
Rb	107.7 ± 9.0	-
S	98.0 ± 5.4	-
Se	105.6 ± 24.7	-
Sr	45.1 ± 2.5	-
Tl	<DL	-
U	83.8 ± 13.9	-
V	77.1 ± 4.6	-
Zn	85.4 ± 6.0	-